OUTLINES OF PHYSIOLOGY

JONES, EDWARD GROVES, 1874-

Christmas 2023

To Campbell -
With love and wishes
for a successful
career in the medical
field!
Mimi

This book is a
reproduction written
by your great, great
grandfather and
published in 1907 when
he was 27 years old -
Dr. Edward Groves Jones
The original can be
found in the Library
of Congress.

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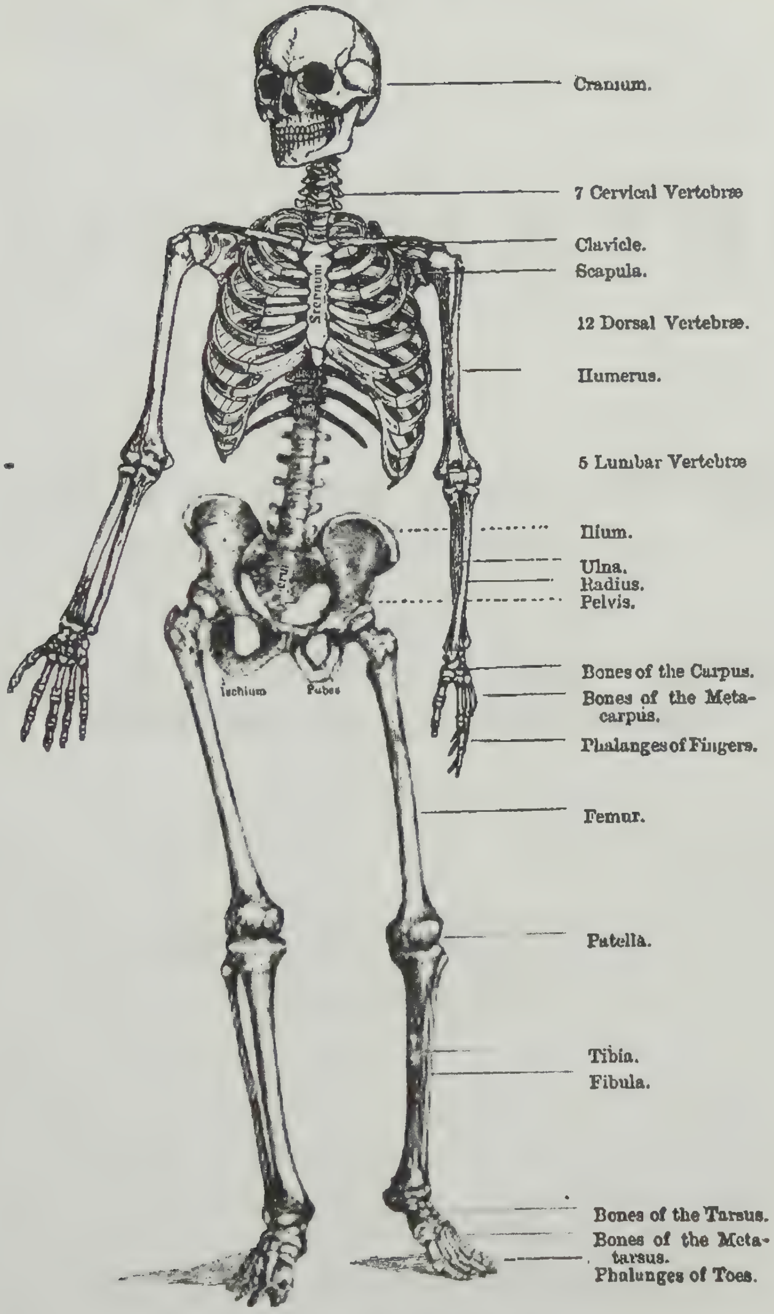
JONES AND STEPHENS



THE SKELETON (after Holden).

OUTLINES

OF

PHYSIOLOGY

BY

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AND

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SECOND EDITION, REVISED

107 ILLUSTRATIONS

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TO

DOCTOR WILLIAM S. KENDRICK,

PROFESSOR OF MEDICINE IN THE ATLANTA SCHOOL OF MEDICINE,

THESE PAGES ARE AFFECTIONATELY DEDICATED.

Dedicated to Dr. Jones'
uncle. He left his
family farm in Chattooga
County, Georgia at age 13
to study medicine in
Atlanta Georgia. Dr. Jones
went on to hold the Chair of
Surgery at Emory University.

PREFACE TO SECOND EDITION.

In revising Dr. Jones' work I have endeavored to make a more systematic arrangement of the different chapters, thus presenting the book to students in a slightly different form than originally. The **Introduction** and the chapters on **Circulation** and on the **Chemical Constituents of the Body** have been entirely rewritten. A new Chapter entitled **The Blood** has been inserted as a fore-runner to the Chapter on the **Circulation,** it being thought best to understand what the fluid is that circulates before its circulation is investigated.

Different minor changes have been made throughout the book wherever it was thought appropriate to rearrange or reconstruct sentences, or to eliminate unimportant pages.

With these few exceptions the book remains as Dr. Jones originally planned and the bulk of his work admits of only favorable criticism. I am indebted to Dr. Stewart R. Roberts for valuable assistance and suggestions, and to the works of Tigerstadt, Kirkes, and Schenck and Gürber.

ROBERT G. STEPHENS.

Atlanta, Georgia,
December, 1907.

PREFACE TO FIRST EDITION.

THIS volume has been prepared with the view of presenting, in as convenient form as possible, the essential facts of modern physiology as related to the practice of medicine. In the execution of this purpose brevity has been made a prime consideration; therefore, such details as are of secondary importance are omitted, theories are avoided, and conclusions are recorded without argument. There is no short road to knowledge, and it would be unfortunate should such a book as this in any way discourage extended research; but students in college have none too much time to devote to any one subject, and any simple collection of pertinent facts, however brief, can, if reliable, be used to great advantage. I have endeavored, however, to make the work sufficiently exhaustive to be self-explanatory, believing that otherwise economy of expression is practiced at the expense of the reader's interest.

A maximum of space has been given to those subjects which seem of most practical importance. The chemistry of the body, the special senses and embryology have not been treated in great detail. It has been thought undesirable to omit a brief anatomical description of the separate organs discussed.

In the preparation of this volume no claim to original investigation is made. The writings of various authorities have been freely drawn upon. Especial acknowledgment is due to the following authors: Howell (American Text-Book), Halliburton (Kirkes' Handbook), Flint, Verworn and Stewart.

I am under obligations to Dr. J. Clarence Johnson, whose lectures have been of great value to me, and to Dr. Frank K. Boland, who has written the whole of Chapter II., read the proof sheets, and rendered other valuable assistance in connection with the work.

ATLANTA, GA. E. G. J.

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INTRODUCTION.

Biology is the science of life and includes that of both ani-

ERRATA.

Page 5.	Line 18, for "(CO)" read "(CO_2)"
Page 6.	Line 20, for "comes" read "come"
Page 8.	Line 5, omit words "by the action"
Page 70.	Line 1, for "is" read "are"
Page 76.	Line 7, for "vein" read "veins"

The science dealing with the phenomena of normal life is called **Physiology.** Any departure from the normal phenomena is called **Pathology.** Physiology is either animal or vegetable.

The unit for all physiological action is the **cell.** Cells combine and each cell in the combination contributes a small part to the action of the whole. This combination of cells for the performance of some particular function is called an **organ.**

An organ may be said to be a combination of cells that perform a definite phenomenon or function.

INTRODUCTION.

Biology is the science of life and includes that of both animal and vegetable life. The science dealing exclusively with animal life is called **Zoology,** and that dealing exclusively with vegetable life is called **Botany.**

To study the science of life it is necessary that the structure and compilation of the animal and vegetable bodies be understood. This study of the gross outlines, forms, and structure is called **Morphology** or **Anatomy.**

After the structure and outline of a body is investigated, naturally the question arises as to why it is so constructed and for what purpose it is so arranged. A certain particular portion is observed and a certain phenomenon is noted occurring in it each time. Another body is brought under observation and the analogous portions in it investigated with the result that precisely the same phenomenon occurs in it as in the first. Thus the investigation is continued until this particular phenomenon occurs in so many different bodies in like structures that it becomes the rule for these structures. Then we call this phenomenon the **function** of that structure in which it invariably occurs.

The science dealing with the phenomena of normal life is called **Physiology.** Any departure from the normal phenomena is called **Pathology.** Physiology is either animal or vegetable.

The unit for all physiological action is the **cell.** Cells combine and each cell in the combination contributes a small part to the action of the whole. This combination of cells for the performance of some particular function is called an **organ.**

An organ may be said to be a combination of cells that perform a definite phenomenon or function.

Chemical elements compose the structures of the cells and both chemical and physical laws govern their acts. The forces resulting from the activity exerted in response to chemical and physical laws is **Life.** This activity lies in the cell, but the mystery of its action has never been solved. When the cell is reached investigation seems to be unable to lift the veil and show just what are the forces making life.

For system in arrangement and convenience of study, four divisions of Physiology may be made. These divisions cannot have exact boundaries separating them, for they are interdependent and to grasp one another has to be considered. These divisions are:

(1) Structural Physiology
(2) Functional Physiology
(3) Nervous Physiology
(4) Reproductive Physiology.

1.—Structural Physiology.—The body is composed of chemical elements and conforms to chemical and physical laws as any other chemical or physical body. An understanding of its structure is essential to an understanding of its various activities.

2.—Functional Physiology.—We have just dwelt on the necessity of knowing the composition of the animal in order to appreciate its functions. The interdependence of structure and function is marked and the understanding of one is essential to a grasp of the other.

We shall endeavor under Functional Physiology to show how the various chemical and physical structures perform their duties. The body takes in food, the organs in functionating appropriate it. The blood is manufactured, the organs in functionating, circulate it. The organs have structure and the products of their activity have structure and it is the nature of this structure that makes the organic activity possible. Thus again structure and function are interwoven.

3.—Nervous Physiology.—The nervous system is the portion of the body that controls its activities. It is physical in outline, chemical in structure, but its activity is a force not understood. It is governed by the mind. All the actions of the body are controlled by it and no function is performed unless either voluntarily or involuntarily directed by the nervous system.

4.—Reproductive Physiology.—All life is hereditary and a new being is the product of two elements from two living beings. Every cell springs from a cell already in existence. To show how certain organs functionate in order to produce new cells is the object of the division on reproduction.

As hinted at above the study of Physiology embraces the phenomena occurring in vegetable bodies as well as those occurring in animal. To understand human physiology it is necessary to begin with plant physiology and ascend step by step, for plants grade off into animals and it is important to contemplate all as a whole. In the following pages, however, we must confine ourselves to animal physiology and especially to that division which deals with the phenomena occurring in human beings.

OUTLINES OF PHYSIOLOGY.

CHAPTER I.

THE CHEMICAL STRUCTURE OF THE HUMAN BODY.

THE human body is a structure made up of chemical elements either free or in compound. We find Carbon, 18.5 per cent; Hydrogen, 11 per cent; Oxygen, 65 per cent; Nitrogen, 2.5 per cent; which are the most important constituents and compose 97 per cent of the whole. The other three per cent is made up of Sulphur, Phosphorous, Chlorine, Iodine, Fluorine, Silicon, Potassium, Sodium, Calcium, Magnesium, and Iron. Of all these elements only Hydrogen, Oxygen and Nitrogen are found in the free state, and only the Oxygen is of any physiological importance when thus found.

These constituents of the body may be divided into two classes according to their importance from the standpoint of activity. These classes are :—

1.—**Compounds that furnish no energy to the body for performance of its functions.**—These are saturated compounds and are chiefly valuable in a physical way, although they do enter into the formation of the different chemical compounds.

2.—**Compounds that furnish energy to the body.**—These are not saturated compounds and are capable by chemical changes of transmitting their stored up energy to cause the body to perform its different energies.

Besides these two classes of the constituent compounds of the body there is another class distinct to itself. This is a class composed of the products resulting from the physiological combustion that is constantly going on. These are the end-products of metabolism and are to be excreted from the body.

1. Compounds not Yielding Energy.

(1) Water, (2) Acids, (3) and Salts are the examples of this class of compounds.

(1) Water.—Composes somewhere between 65 per cent—70 per cent of the body and is important on account of its :—

(a) Solvent Power.—It holds different chemical elements in solution and makes diffusion of food-stuff possible.

(b) Temperature-regulating Power.—By evaporation from skin and lungs the temperature is controlled by radiation.

(c) Splitting-up Power.—It gives up its Hydrogen readily and thus forms new energy-yielding chemical compounds.

(2) Acids.—Carbonic Acid (CO) and Hydrochloric Acid (HCL) are found free in the body. The Carbonic Acid is in the blood and the Hydrochloric Acid is liberated from Sodium Chloride (NaCl) by the action of the glands of the stomach. It is found free in the gastric juice.

Bases are not found free but are in union with acids as :—

(3) Salts.—When tissue is incinerated the salts remain as an ash. The principal salts are :—

(a) Sodium Chloride.—This salt is found in the fluids of the tissues and to a small degree in the cells. It is important because it dissolves certain proteids and controls the osmotic pressure of the fluids of the tissue.

(b) Potassium Chloride.—This is also important from the part it plays in osmosis.

(c) Sodium Carbonate.

(d) Bicarbonate of Soda —This is important as a carrier of Carbonic Acid.

(e) Potassium Phosphate.—This is the most important salt in cell structure.

(f) Neutral Calcium Carbonate.—This is found in the bony structures and as the crystals of the spermatic fluid.

(g) Acid Calcium Carbonate.—This is also important because it is the carrier of Carbonic Acid gas.

(h) Neutral Calcium Phosphate.—This is the chief mineral constituent of the skeleton, forming one-fifth of it.

(i) Acid Calcium Phosphate.—This is supposed to be important in the coagulation of the blood.

(j) Magnesium Carbonate and Magnesium Phosphate.—These are both constituents of the skeleton.

2. Energy Yielding Compounds.

These compounds are divided into (1) Carbo hydrates, (2) Fats, and (3) Proteids.

1.—Carbohydrates.—These contain Carbon, Hydrogen, and Oxygen, the Hydrogen being in the same proportion to Oxygen as it is in water. Under this head comes the starches; the different sugars as lactose, maltose, glucose; the fibrous structure, cellulose, which makes up sheaths of muscles and walls of cells; and glycogen of the liver and muscles.

2.—Fats.—The Fats are products of fatty acid and glycerine. The most important fatty acids are Palmitic Acid, Stearic Acid, and Oleic Acid.

The Fats for the most part are found inclosed in the fatty tissue cells. This is the adipose tissue. Fat is found in the blood and in other fluid constituents of the body in small quantities.

Cholesterin is an important fat being found chiefly in the cells of the nervous system.

Fats are of importance in the body, because of their:—

A.—Protection.—They act as cushions and prevent unnecessary jars to certain organs, as eye and kidneys.

B.—Poor Conductivity.—They are poor conductors of heat and thus shield the body from too rapid cooling.

C.—Easy Combustion.—They release heat and energy very readily.

3.—Proteids.—Tigerstadt says: "We know nothing concerning the chemical constitution of living substance. Chemical investigation of dead animal and plant bodies has made us acquainted with a very large number of different......compounds; but not even the delicate micro-chemical reactions have been able to furnish any information on the chemical nature of living substance. We can only say, therefore, that when the living substance dies we are able to demonstrate proteid bodies of different kinds as the chief constituents and that in animals at least the living substance can be formed, as it appears only from proteid bodies."

Thus it seems the Proteids are the chief constituents in the animal body. They are composed of the five elements, Carbon, Hydrogen, Oxygen, Nitrogen, and Sulphur. Besides these we have Phosphorous, Iron and other constituents, but they are not essential to the formation of the proteid body.

The Proteids are the nitrogenous compounds and are of marked importance because of this fact. All tissues and organs are formed of them. The proteids are (A) Simple and (B) Compound.

(A) A Simple Proteid is one of the formula CHONS and not compounded with other substances. Egg-albumen is a simple proteid.

(B) A Compound Proteid is a Simple Proteid united to another substance forming a new compound. Hemoglobin, Nucleo-albumin, and the neucleins are all compound proteids.

Simple Proteids are divided into (a) Native Proteids which

are obtained from the body by chemical reaction on the different tissues, as the albumins, the globulins and the mucins.

(b) Those separated from some compound, as the globin from hemoglobin.

(c) Those resulting from the action on proteids by the action of digestive juices, as the proteoses, and albumoses.

Proteid bodies have several characteristics. One is, when suitable conditions of heat and moisture prevail, they undergo putrefaction. Another is, they coagulate at temperature of 130 and over and by the addition of acids.

The chemical constituents of the body govern the character of the food stuffs that are necessary for the life of the body. In giving the different classes of the body-constituents, at the same time is given the food that, in one form or another, must be appropriated by the tissue cells.

CHAPTER II.

THE CELL AND THE ELEMENTARY TISSUES.

(A) THE CELL.

All the tissues of the body are made up of cells and intercellular substance. All the cells are descended from one parent cell, called the ovum, while the intercellular substance is created through the medium of the cells.

Fig. 1.

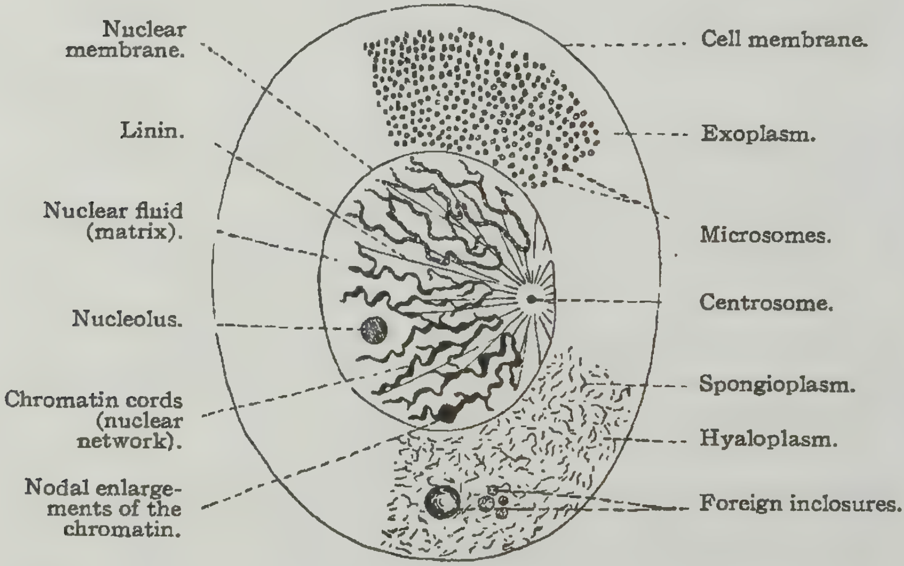


Diagram of a cell.

Microsomes and spongioplasm are only partly drawn. (*Brubaker.*)

A **cell** may be defined as an irregularly round or oval mass of protoplasm of microscopic size, enclosing usually a small indis-

tinct spherical body, the nucleus. While these are the typical cell elements, cells often possess a thin wall, or surrounding membrane, and the nucleus may contain one or more smaller bodies, called nucleoli.

The greater part of the cell contents is **protoplasm.** This is a gelatinous or semi-fluid, granular substance, transparent, and generally colorless. It is not a homogeneous mass, but is composed of an elastic network, called the *spongioplasm*, enclosing a less firm portion, the *hyaloplasm*. Chemically protoplasm consists of various albuminous substances, and a special nitrogenous proteid, *plastin*, together with water and salts.

The part played by the **nucleus** in the reproduction of the cell gives it great importance. It is a specialization of protoplasm, traversed by a network of fibrils, enclosing a probably semi-fluid portion, the *matrix*. The name *chromatin* is often given to the fibrils, from their affinity for certain stains, while the matrix, which does not take these stains, is termed *achromatin*. The nucleus has a limiting wall or membrane, and often contains one or more smaller bodies, *nucleoli*, concerning which but little is known. A small body, the *centrosome*, lies usually just outside the nucleus. It is most prominent when cells are dividing or about to divide, and has been supposed to give the primary impulse to karyokinesis, but this is not certain. It has an attractive influence on the protoplasmic fibrils in the neighborhood producing the "attraction sphere" (see Fig. 1).

Nuclei are especially distinguished: (*a*) By their resisting the power of certain acids and alkalies (*e. g.*, acetic acid), by which they are rendered more clearly visible under the microscope. This indicates some chemical difference between the protoplasm of cells and that of nuclei, since the former is destroyed and rendered invisible by these reagents. (*b*) By staining in hematoxylin, carmine, etc.

Nuclei are round or oval, and may occupy any position in the cell. They are more constant in size and shape than the

cell itself, but sometimes may occupy nearly the whole of that body.

Properties of Cells.—The properties of cells in general are (1) *motion*, (2) *irritability*, (3) *nutrition*, (4) *growth* and (5) *reproduction.*

1. *Motion*—This manifestation is well illustrated in its lowest form by a fresh-water organism, the ameba, the movement of which is called *ameboid.* In this, the cell, which has hitherto remained smooth in outline, throws out little projections from its body, like limbs, into which the protoplasm gradually streams, thus radically changing the shape of the cell, and finally its position. Higher degrees of motion are seen in the contraction of muscle cells and the waving of cilia.

2. *Irritability.*—The ameboid movement of cells is spontaneous, but motion may also be excited by external influences, viz., thermal, mechanical, nervous, chemical and electrical.

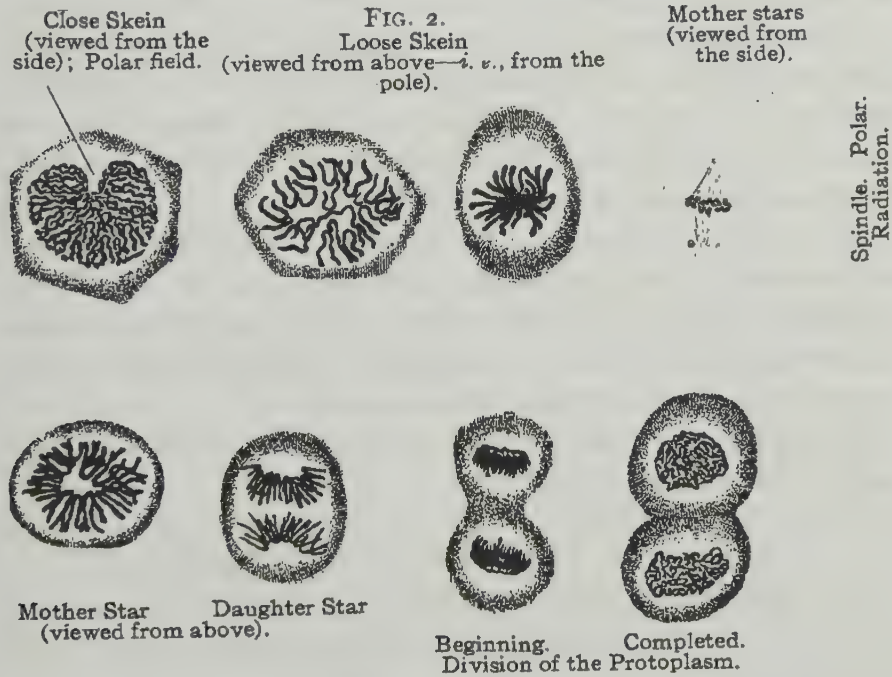
3. *Nutrition* includes the wonderful processes of anabolism and katabolism, by which cells take in certain foods and so change them as to nourish and build up their tissue, and throw out the parts which cannot be used

4 *Growth* follows as a natural sequence of proper nutrition, and may cause a uniformly increased element; but in higher organism, growth is usually unequal, to which phenomenon the specialization of cells is due. Thus cells assume special forms or special functions: some become nerve, others bone, some develop the power to contract, others to secrete, etc.

5. *Reproduction.*—By this property cells are enabled to reproduce themselves. There are two methods, by (*a*) *direct* and (*b*) *indirect* division. In the first the cell divides into two by the simplest method possible, the nucleus and cell protoplasm constricting in the center until two cells are formed This is an unimportant method in the higher animal life we are studying. The chief manner of reproduction in animal cells is by indirect division, known as *karyokinesis* or *mitosis.*

In the beginning of this phenomenon, the nucleus, which plays the important rôle, grows larger. Its chromatin greatly increases and becomes contorted so as to form a dense convolution, the *close skein*, or *spirem*. Then the chromatin fibrils further thicken, but become less convoluted, forming irregularly arranged loops, the *loose skein*. During the formation of these

FIG. 2.



Karyokinetic figures observed in the epithelium of the oral cavity of a salamander.

The picture in the upper right-hand corner is from a section through a dividing egg of Siredon pisciformis. Neither the centrosomes nor the first stages of the development of the spindle can be seen by this magnification. × 560. (From *Brubaker*.)

skeins the nuclear membrane and the nucleoli disappear. The fibrils of the loose skein now separate at their peripheral turns into a score of loops, the closed ends of which point toward a common center—a clear space called the *polar field*. Seen from above these loops of chromatin make a wreath called the *mother wreath;* seen from the side, they make a star, called the

mother star or *aster*. While the loose skeins are forming, delicate striæ appear within the achromatin, so disposed as to make two cones with their bases within the polar field and directed toward one another, and their apices directed toward the future new nuclei. These achromatin figures constitute the *nuclear spindle*. They then arrange themselves into two *daughter wreaths* or asters, similar to the mother. At this juncture the cell protoplasm begins to divide by becoming constricted in the center. The daughter stars are converted into two new nuclei, in inverse order as the original nucleus was broken up. First the loose skein forms, then close skein. Nuclear membranes and nucleoli appear, the cell protoplasm divides into two new cells, and the cycle is completed. (See Fig. 2.)

Derivation of Tissues.—The primary parent cell divides into an innumerable mass of cells, which is called the *blastoderm*. The blastoderm soon divides into two more or less distinct layers, an outer and inner, named *ectoderm* and *entoderm*, between which a middle layer later appears, the *mesoderm*.

All the tissues of the body develop, by specialization, from these three. (See Embryology.)

(B) THE ELEMENTARY TISSUES.

Four varieties of elementary tissues are usually named, (1) epithelial, (2) connective, (3) muscular and (4) nervous.

1. The Epithelial Tissues.

Epithelium is a tissue consisting of one or more layers of cells covering all the free surfaces of the body. That covering the skin and mucous membranes is (1) *epithelium proper*, while that covering the serous membranes is known as (2) *endothelium*.

1. Mucous membranes secrete a tenacious fluid known as mucus, and furnish a lining surface for all tracts with external openings, *i. e.*, the digestive, respiratory and genito-urinary tracts.

2. Serous membranes secrete a watery fluid which acts as a lubricant for the walls of closed sacs to move smoothly against one another. They line those surfaces without direct external openings, such as the pleura, pericardium, peritoneum, heart and blood-vessels, synovial surfaces of joints, lymphatic spaces and vessels, etc.

Epithelial tissue performs various functions in different parts of the body. In the skin, where it is known as epidermis, it protects the delicate surface of the true skin beneath; in the alimentary and genito-urinary canals it aids in secretion and excretion; in the respiratory tract it preserves an equable temperature by the moisture it produces, while in all internal parts it yields lubricants.

Epithelial cells are connected together by an interstitial cement substance. They contain no blood-vessels and no nerves, being nourished by absorption through clefts of this substance. The tissue usually rests upon a basement membrane or *membrana propria*, which is a modification of the connective tissue beneath

Varieties.—The varieties of epithelium may be classed as follows: (I) **Squamous,** (*a*) *simple*, consisting of a single layer, (*b*) *stratified*, consisting of several layers; (II) **Columnar,** (*a*) *simple*, (*b*) *stratified;* (III) **Modified,** (*a*) *ciliated*, (*b*) *goblet*, (*c*) *pigmented*. (*d*) *glandular*, (*e*) *neuro-epithelium*.

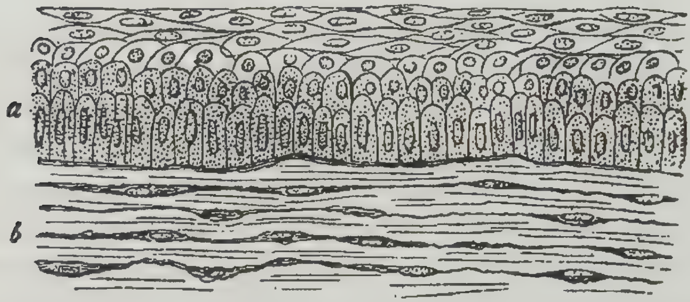
I. **Squamous Epithelium.**—(*a*) As a *simple* layer this occurs in but few places, lining the air sacs of the lungs, the mastoid cells, membranous labyrinth, and crystalline lens. Viewed from above it appears as flattened, polyhedral nucleated plates like a regular mosaic.

(*b*) *Stratified* squamous epithelium is far more common. This we find covering the true skin, the cornea, mouth, lower part of the pharynx, esophagus, epiglottis and upper part of the larynx and all the urethra in both sexes, except the membranous and penile portion in the male.

The arrangement of the cells is typified in the epidermis.

The lowest layer of this variety, resting upon the membrana propria, is almost columnar in type. As they approach nearer the surface, the layers become flatter and more scale-like, and possess less vitality. As the outer layer is worn away, the

FIG. 3.



Vertical section of the stratified epithelium of the rabbit's cornea.

a, anterior epithelium, showing the different shapes of the cells at various depths from the free surface; *b*, a portion of the substance of cornea. (*Kirkes* after *Klein*.)

lower, more vigorous layers push upward to the surface to take its place. In the middle strata, where the cells are polyhedral in shape, we find the so-called *prickle cells*, which have minute projecting spines, by which they are connected with one another.

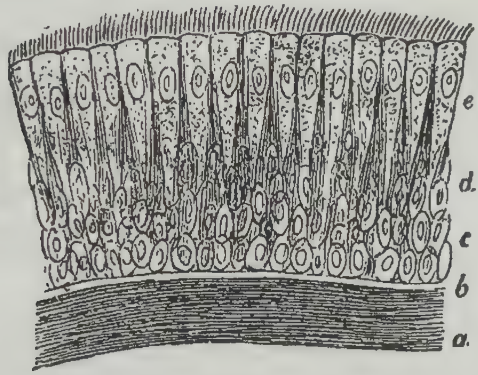
II. **Columnar Epithelium.**—This type consists of column or rod-shaped cells, set upright, longitudinally striated, and containing oval-shaped nuclei.

Ciliated epithelium is more common with this variety than with any other. Each of these cells presents, on its free surface, twenty or more small hair-like, protoplasmic appendages, called *cilia*. During life these small processes are in constant rapid motion, waving in a direction towards the outlet of the cavity in which they are found. In the genital organs they are important in bringing together the male and female elements of reproduction, while in the respiratory tract they are concerned

in aiding the passage of the mucus and in the expulsion of foreign bodies.

1. *Simple* columnar epithelium occurs in the alimentary tract from the stomach to the anus, mammary glands, seminal ves-

FIG. 4.



Ciliated epithelium of the human trachea.

a, layer of longitudinally arranged elastic fibers; *b*, basement membrane; *c*, deepest cells, circular in form; *d*, intermediate elongated cells; *e*, outermost layer of cells fully developed and bearing cilia. × 350. (*Kirkes* after *Kolliker*.)

icles and ejaculatory ducts, membranous and penile portions of the urethra.

This variety is found ciliated in the greater part of the uterus, and in the brain-ventricles and canal of the spinal cord.

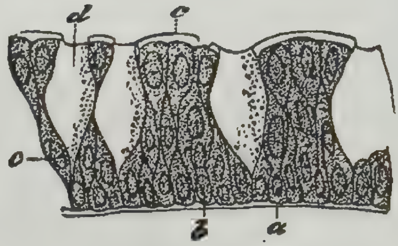
2. *Stratified* columnar epithelium occurs in the last part of the vas deferens and the olfactory part of the nasal fossæ. Ciliated, it occurs in the Eustachian tube, lachrymal ducts, respiratory part of nasal fossæ, ventricle of larynx, trachea and bronchi, epididymis and first part of vas deferens.

III. **Modified Epithelium.**—(*a*) The *ciliated* variety has been considered.

(*b*) *Goblet* cells are found on all surfaces covered by columnar epithelium, but especially in the large intestine. They secrete mucin, the main constituent of mucus, which so distends the cell that it ultimately bursts and the mucus is discharged.

(*c*) Foreign matters, such as fat, proteid, etc., often invade the protoplasm of epithelial cells. When these matters are colored, the epithelium becomes *pigmented.* Such cells are constant in the deeper layer of the epidermis, especially of certain races, and in the choroid coat of the eye.

FIG. 5.



Epithelial cells.

Some of which are filled with mucus, *d*, forming goblet-like gells. (From *Yeo* after *Cadiat.*)

(*d*) *Glandular* epithelium may be columnar, spherical or polyhedral in shape. It is found lining the terminal recesses of secreting glands. The protoplasm of the cell usually contains the materials which the gland secretes.

(*e*) The epithelium covering those parts towards which the nerves of special sense are directed is epithelium of the highest specialization. It is known as *neuro-epithelium*, and occurs in the retina, the membranous labyrinth and in the olfactory and taste cells.

2. The Connective Tissues.

These tissues, though developed from the same embryonal elements, present varieties differing widely in appearance and properties. They all serve the same general purpose in the animal economy—that of furnishing a supporting and connecting framework for the body. Like the other elementary tissues they consist of two elements, *cells* and *intercellular substance*, the latter being far the greater in amount.

Connective tissue *cells* are of two kinds, *fixed* and *wandering.* The former are protoplasmic plates of stellate appearance, with a nucleus occupying the thick part of the cell, from which branched processes extend. They sometimes are pigmented, as in the choroid and iris. Wandering or migratory cells are pres-

ent in many situations. These are larger than the fixed variety, and are possessed of typical ameboid movement.

The divisions of connective tissue are: I. *Fibrous Connective Tissue;* II. *Cartilage;* III. *Bone;* IV. *Blood.*

I. **Fibrous Connective Tissue.**—This variety is subdivided into (A) *White Fibrous*, (B) *Yellow Elastic*, and (C) *Areolar*, to which three special forms may be added, (*a*) *Mucoid* or *Gelatinous*, (*b*) *Adenoid* or *Retiform*, and (*c*) *Adipose*.

(*A*) *White Fibrous Tissue.*—This is a true connective tissue, and forms ligaments, tendons, and membranes. Examples of the last are the muscle fasciæ, periosteum, and the investing

FIG. 6.

Bundles of the white fibers or areolar tissue partly unravelled. (*Kirkes* after *Sharpey.*)

sheaths of glands and nerves. It possesses no elasticity, but great strength, and appears as parallel white glistening fibers in tendons and ligaments, and as intersecting fibers in membranes.

(*B*) *Yellow Elastic Tissue* is characterized by its marked elasticity, and is found in the vocal cords, longitudinal coat of the

trachea and bronchi, inner coat of blood-vessels, especially the large arteries, and in some ligaments. Its yellow-tinted fibers are seen in parallel waves and are larger than those in the white tissue. They sometimes form a web-like layer, as in the fenestrated membrane of Henle in the arteries.

FIG. 7.

A teased preparation of connective tissue,

Showing fine and coarse elastic fibers mingled with bundles of fibrillar tissue and connective tissue corpuscles. (*Yeo.*)

(*C*) *Areolar Tissue* is widely distributed and constitutes the connecting layer beneath the skin, submucous and subserous tissues, and between muscles. It receives its name on account of the areolæ or spaces within its substance, which admit the adjacent parts to move easily upon one another. It consists of white and yellow fibers in about an equal proportion.

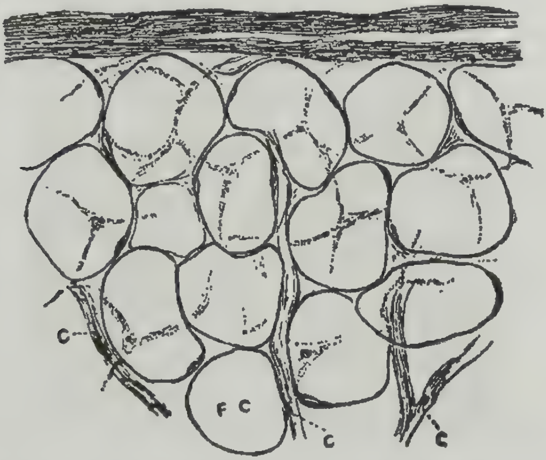
(*a*) *Mucoid or Gelatinous Tissue* forms the "jelly of Wharton" in the umbilical cord, and is found in other situations in the fetus, and in the vitreous humor of the eye in the adult.

(*b*) *Adenoid Tissue.*—This consists of a very delicate network of fibers, and is found in mucous membranes and forming the reticulum or framework of the spleen and lymphatic glands.

(*c*) *Adipose, or Fatty Tissue,* exists in nearly all parts of the body, except the subcutaneous tissue of the eye-lids, the penis

and scrotum, nymphæ, within the cavity of the cranium, and in the lungs except near the roots. It is nearly always found within

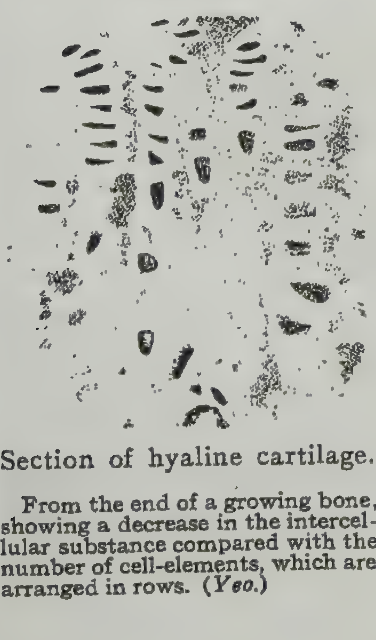
FIG. 8.



Group of fat-cells (F C) with capillary vessels (C). (*Kirkes* after *Noble Smith.*)

the meshes of areolar tissue, where it forms lobules of fat. Fatty matter, in the form of oily, and not distinct adipose, tissue, is found in the brain, liver, blood and chyle. The tissue is densest beneath the skin, especially of the abdomen, around the kidneys, on the surface of the heart between the furrows, and in bone marrow. Its blood supply is rich.

FIG. 9.



Section of hyaline cartilage.

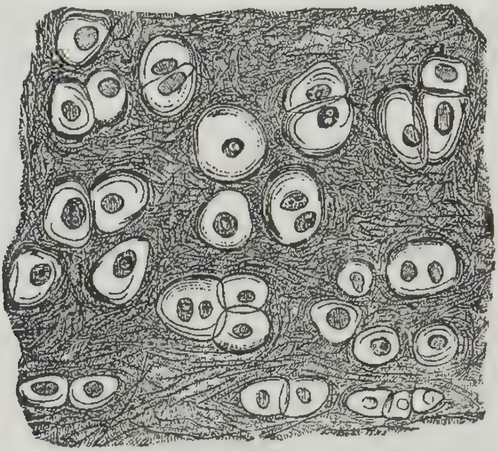
From the end of a growing bone, showing a decrease in the intercellular substance compared with the number of cell-elements, which are arranged in rows. (*Yeo.*)

II. **Cartilage.**—There are three forms, (*A*) *Hyaline*, or *true*, (*B*) *Yellow elastic* and (*C*) *White fibrous*.

(*A*) *Hyaline* is the typical variety. It forms the articular surfaces of bones, the costal cartilages, and the larger cartilages of the larynx, trachea and bronchi, nose and eustachian tube. In the em-

bryo this cartilage forms nearly the whole of the future bony skeleton. It is of firm consistence, considerable elasticity, and pearly blue in color. It is enveloped in a fibrous membrane, the

FIG. 10.

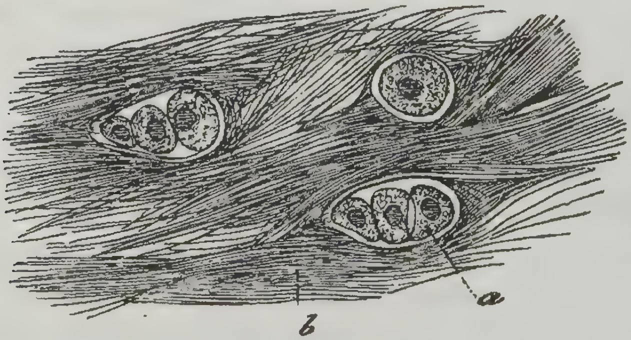


Elastic fibro-cartilage,

Showing cells in capsules and elastic fibers in matrix. (From *Yéo* after *Cadiat.*)

perichondrium, from the vessels of which it derives its nutrition. Like all cartilage, it is composed of *cells* imbedded in a *matrix*

FIG. 11.



White fibro-cartilage,

Showing cells, *a*, in capsules and fibrillar matrix, *b*. (*Yeo* after *Cadiat.*)

The cells are irregular in outline, and arranged in patches o various shapes.

(*B*) The *yellow elastic* type exists in the external ear, epiglottis, cornicula laryngis, and eustachian tube. The matrix is composed almost entirely of fine fibers very much like the yellow variety of elastic tissue.

(*C*) In *white fibrous* cartilage the matrix is made up almost entirely of white fibrous tissue. It is found as: (1) *interarticular fibro-cartilage*, in the semilunar cartilage of the knee-joint; (2) *circumferential*, on the edge of the acetabulum and glenoid cavity; (3) *connecting*, between vertebræ; (4) *stratiform*, forming a coating to grooves on bones, through which tendons glide.

On boiling, cartilage yields a substance, known as *chondrin*, which on cooling turns to gelatin.

III. **Bone.**—Bone is a dense form of connective tissue constituting the skeleton or framework of the body. It serves to protect vital organs in the skull and trunk, and acts as levers in the limbs worked by muscles. The tissue is characterized by the deposit of calcareous or lime matters within its intercellular cement substance, to which its well-known hardness is due. We find in bone two distinct kinds, dense or compact, forming the outer portion, and spongy or cancellous, forming the inner portion.

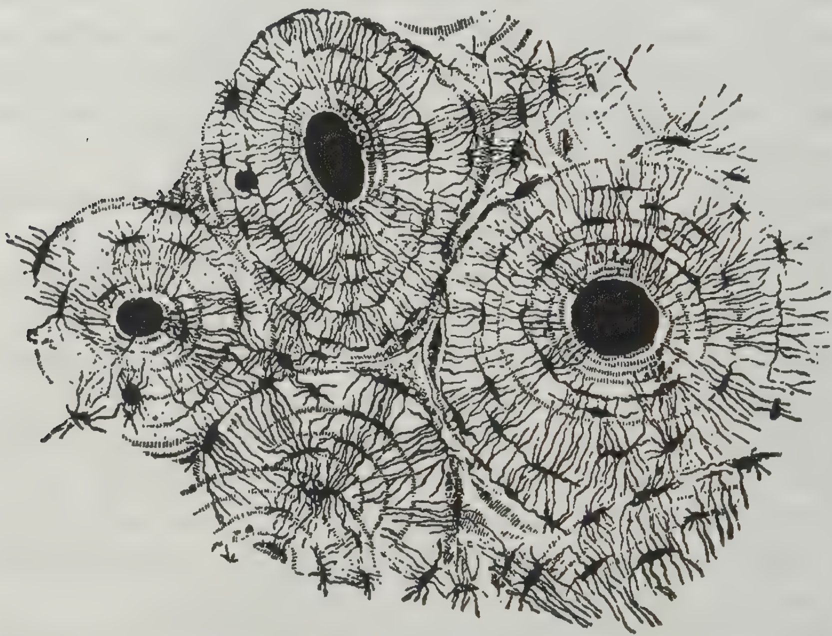
Microscopically bone is seen to consist of many minute longitudinal channels, called *Haversian canals*, each surrounded by concentric layers of bone called *lamellæ*, within which run still smaller longitudinal channels, called *lacunæ*. Connecting the main canal and the lacunæ, and radiating in all directions between them, are other very minute channels known as *canaliculi*. Each Haversian canal, with its surrounding lamellæ, lacunæ and canaliculi, composes an *Haversian system*. (See Fig. 12.)

Periosteum forms the membranous covering of the outer surface of all bones except their articular extremities. It consists of an outer and an inner layer. The outer is a dense fibrous coat protecting the more important internal structure called the

osteogenetic layer, from its intimate connection with the development of bone. It possesses a rich blood supply which nourishes the subjacent bone, and contains numerous cells which later become bone-forming elements—the *osteoblasts*.

Bone marrow is the highly vascular substance found within the central cavity of the long bones and the Haversian canals. That of the adult long bone is a yellow in color, and is composed mainly

FIG. 12.



Transverse section of compact bony tissue (of humerus.)

Three of the Haversian canals are seen, with their concentric rings; also the lacunæ, with the canaliculi extending from them across the direction of the lamellæ. The Haversian apertures were filled with air and débris in grinding down the section, and therefore appear black in the figure, which represents the object as viewed with transmitted light. The Haversian systems are so closely packed in this section that scarcely any *interstitial* lamellæ are visible. × 150. (*Kirkes* after *Sharpey*.)

of fat, while that occupying the spaces of cancellous tissue is red, profuse in blood supply, and contains but little fat. Large, multinucleated cells are found in red marrow, and are known as giant cells, or *osteoclasts*. They are supposed to be concerned in the absorption of bone tissue.

FIG. 13.

Two fibers of striated muscle,

In which the contractile substance, *m*, has been ruptured and separated from the sarcolemma, *a* and *s*; *p*, space under sarcolemma. (From *Yeo* after *Ranvier*.)

Development of Bone.—According to its development from the embryo, bone may be classed as: (*a*) *Endochondral*, derived from the primary cartilage, hyaline in type; (*b*) *Periosteal*, derived from the primary peripheral periosteum. All the bones belong to the former group, except those of the vault of the cranium (parietal and frontal) and of the face and a part of the lower jaw.

The process of bone formation is a complicated one. The osteoblasts are the main agents, whether the bone be derived from cartilage or from periosteum. These cells arrange themselves in different locations, the so-called centers of ossification, over the surfaces of the cartilaginous network or periosteal fibers, as the case may be, and soon are transformed into bone-cells, embedded in a matrix, which is at first soft and finally becomes ossified from the deposit of lime salts.

IV. **Blood.**—The blood is classified as a connective tissue with a liquid intercellular constituent.

3. The Muscular Tissues.

There are two variations of muscular tissues: (*A*) *Striated* or *Voluntary*, and (*B*) *Non-striated* or *Involuntary*. The muscle of the heart is striated, but involuntary.

(*A*) **Striated muscle,** or voluntary, so

called because it is controlled by the will, constitutes the extensive muscular system of the skeleton, and of the walls of the abdomen, besides a few of the muscles connected with certain organs, the middle ear, tongue, pharynx, larynx, diaphragm, generative organs, etc.

This variety of muscle is composed of bundles of fibers, called fasciculi, each enclosed in a net-like sheath, the *perimysium.* Between the fibers is a delicate cementing substance, the *endomysium.* A layer of areolar tissue, of variable thickness, known as the e*pimysium*, surrounds the entire muscle.

Each fiber consists of the *sarcolemma*, or investing sheath, the muscle substance, and the muscle nuclei. The sarcolemma is a tough, homogeneous, elastic membrane, very tightly adherent to the substance of the muscle. The nuclei are oval or fusiform, and lie immediately beneath the sarcolemma, upon the surface of the muscle substance.

Seen under the microscope on longitudinal section voluntary muscle presents alternate light and dark transverse striæ, the explanation of which is a difficult problem, for which many solutions have been offered. That of Rollett seems most plausible. According to this author, striated muscle tissue is composed of darker contractile fibrillæ, arranged in parallel rows of delicate spindles, with a

FIG. 14.

Cells of smooth muscle-tissue from the intestinal tract of rabbit. (From *Yeo* after *Ranvier*.)

A and *B*, muscle-cells in which differentiation of the protoplasm can be well seen.

semi-fluid, lighter portion between, called the *sarcoplasm*. The apposition of the spindles transversely produces the so-called transverse disks. Each spindle terminates in a minute spherical bead, the apposition of which transversely produces the intermediate disks, or *Krause's membrane*. It is to these alternate dark rows of transverse and intermediate disks, with the lighter sarcoplasm between, that the striated appearance of voluntary muscle is due.

The contractile fibrillæ are arranged in bundles or muscle

FIG. 15.

Striated muscular tissue of the heart,

Showing the trelliswork formed by the short branching cells, with central nucle. (*Yeo.*)

columns, surrounded by thick layers of sarcoplasm. On the cross-section these bundles appear in a network of sarcoplasm as minute polyhedral areas, called Cohnheim's areas or fields.

The *blood-vessels* of striated muscles are very numerous. The larger vessels, together with the nerves, are contained within the perimysium, from which the primitive bundles are supplied by

smaller branches. The lymphatic supply is scanty. Nerves are profusely distributed.

(*B*) **Non-striated,** or involuntary muscle forms the coats of the (1) digestive tract from the middle of the esophagus to the anus, (2) capsule and pelvis of the kidney, ureter, bladder and urethra, (3) trachea and bronchi, (4) ducts of glands, (5) gall-bladder, (6) vesiculæ seminales, (7) uterus, (8) blood-vessels and lymphatics, (9) iris, ciliary bodies, and eye-lids, (10) hair follicles, sweat glands, and skin of the scrotum.

Non-striated muscle is made up of bundles of fat, spindle-shaped, nucleated cells longitudinally disposed. Each cell is covered by an elastic sheath, corresponding to the sarcolemma of striated muscle. An endomysium unites the cells together, while a perimysium surrounds the bundles.

Heart muscle is striated and involuntary, and is thus distinguished from the usual form of striated muscle: (1) Its fibers are united with each other at frequent intervals by short branches; (2) the fibers are smaller and the striation is less marked; (3) the sarcolemma is absent; (4) the nuclei are situated within the substance of the fiber and not upon it.

4. The Nervous Tissues.

The primary elements of the great nervous system are, (*a*) the *cells*, which originate nervous impulses, and (*b*) the *fibers* which transmit such impulses, the two being connected and supported by (*c*) the *neuroglia* and *connective tissue framework*.

These tissues will be described under the later discussion of the nervous system.

PHYSIOLOGICAL CHARACTERISTICS OF STRIATED MUSCLE.

Striated muscle possesses *elasticity*, *tonicity*, a peculiar *sensibility*, and *contractility* or *irritability*.

The *elasticity* of muscle is not so much a property of the muscle

substance as of the sarcolemma and interstitial fibrous tissue. There is of course a certain limit to this power, if extended beyond which the muscle fibers become dislocated and unfitted for further use.

Tonicity is the constant insensible tendency to contraction possessed by muscle in a normal and healthy state. This is seen in surgical operations in which muscles after being divided become permanently contracted.

Muscle has a *special sensibility* which enables it to appreciate the force of weight, resistance, immobility and elasticity, and the sense of fatigue after long-continued exertion. General sensibility, as of pain, is but little developed.

Contractility is a property possessed by striated and non-striated muscle. We see it in the former in flexing a limb, raising the eye-brows, etc., and in the latter in the variations in calibre of blood-vessels and the contraction of the uterus in labor. It is noticeable that a voluntary muscle responds so quickly to stimuli that the contraction may be said to be practically instantaneous. The subsequent relaxation occurs as soon as the stimulus is withdrawn. The contraction and relaxation of involuntary muscle is much more sluggish. It is the phenomenon as presented in the striated variety with which we are most concerned.

Muscular contractility results from a stimulus which may be transmitted from the brain through the conductors of motor impulses, as by an act of volition, or it may be produced reflexly, or artificially.

Artificially, the stimulus may be applied through the nerve supplying the muscle, or to the muscle directly, and may be mechanical, thermal, chemical or electrical. Electricity furnishes the most convenient form of stimulus for experimental use, because its force can be accurately regulated.

Muscular contractility can be studied in the dead organism for some time after death, especially in cold-blooded animals.

The power to contract remains the same so long as the nutrition has not been disturbed beyond certain limits. Thus, when the power is lacking in muscles of a living organism from paralysis and disuse, upon minute examination it is found that chemical and physical disintegration has occurred.

The principal changes noted in muscle on contraction are in electrical and chemical phenomena, elasticity, temperature and form.

I. The *electrical* changes involve the so-called "currents of rest." A galvanometer applied to a muscle removed from the body indicates the passage through it of certain electrical currents. When the muscle is made to contract the galvanometric needle returns to zero (the negative variation); when it relaxes the needle again indicates the passage of a current. The *cause* of these currents may be chemical changes due to degenerative processes.

The effects of galvanic and Faradic currents upon muscular *contractions* are indicated under the nervous system.

II. The *chemical* changes are:—

(*a*) Muscle tissue, which is normally neutral or slightly alkaline in reaction, becomes acid, owing to the formation of sarcolactic acid.

(*b*) More oxygen is taken up from the blood than when the muscle is at rest, proof of which is shown by the facts that during active muscular exercise more oxygen enters the body by respiration, and the blood leaving active muscles is poorer in oxygen.

(*c*) More CO_2 is produced in the muscle. The increased elimination of this gas is far in excess of the increased consumption of oxygen. Oxygen is stored up in the same way in the muscular substance in the intervals of activity. It is a condition to be easily called into use when the metabolism incident to contractions begins.

(*d*) Glycogen, which is ordinarily stored up in the muscle substance, is consumed.

(*e*) A peculiar muscle sugar, probably inosite, makes its appearance.

The increased output of CO_2 is in striking contrast to the practically undisturbed elimination of urea, except after *prolonged* exercise. An explanation of this discrepancy will be given under Nutrition.

III. A muscle is not only *elastic* but *extensible*. A passive weight suspended from the end of a muscle will elongate it; but when the weight is removed the muscle resumes its original length. A contracted muscle is more extensible than one at rest. Fresh muscle is perfectly elastic, *i. e.*, it will regain its exact normal shape after contraction, elongation, etc.; but continued activity finally impairs this quality.

IV. Evolution of *heat* accompanies muscular contraction. It will be seen later that all metabolic activity means the production of force, most of which force assumes the form of heat. The increased metabolism in muscle tissue during exercise means an increased conversion of potential energy of the food stuffs into heat and work. The heat produced represents by far the larger part of this potential energy.

Of the total amount of potential energy converted, the part taking the shape of *work* upon conversion is greater the greater the resistance to muscular contraction. It follows that the heat is *relatively* diminished; though the increased metabolism renders it not absolutely so, *i. e.*, the amount of heat *actually* produced is greater the greater the tension. The natural, and correct, conclusion on this ground is that when a muscle becomes fatigued the amount of potential energy taking the form of heat is increased. The heat production of muscular activity is involuntarily made use of when a person shivers in cold weather.

Given a certain amount of work to do, more heat will be evolved if it be done by a few strong contractions than by many weak ones.

V. The changes in *form* are the most striking of those that

occur. In contracting a muscle becomes shorter and broader, the two alterations compensating each other, so that there is no change in bulk. The amount of shortening may vary all the way up to about 35 per cent. of the original length of the muscle. The fresher and more irritable a muscle is the shorter it will become in response to a given stimulus. Up to a certain limit the stronger the stimulus the greater the shortening. Up to about 85° F. heat increases the amount of shortening. The more nearly parallel to the long axis of the muscle the fibers run, the greater the shortening in proportion to the length.

Mechanism of Muscular Contraction.—The application of electricity to the nerve supplying a given muscle, by one of the various apparatus which have been devised for the purpose, shows the mechanism of muscular contraction in a graphic manner. Two varieties of phenomena may be produced by such an apparatus. The stimulus may be applied in the form of a single electrical discharge, when it is followed by a single muscular contraction; or a rapid succession of discharges may be applied, producing a state of permanent, or so-called tetanic, contraction.

Upon the application of a single electrical discharge to a motor nerve connected with fresh muscle, there is a sudden contraction, which is succeeded by a sudden relaxation. Under this stimulation, the muscle shortens its length about three-tenths. In man, the time required for the contraction is estimated at .03 or .04 of a second, and for the relaxation a period a little shorter, with about .004 to .01 of a second for the interval between stimulation and contraction, called the latent period.

Experiments have shown that when one end of a muscle is excited, a contraction occurs at that point and travels along the length of the muscle in the form of a wave, the estimated rapidity of which is thirty-three to forty-three feet per second. In the contraction of a muscle it is believed that shortening of the fiber takes place wherever a stimulus is received, and that this is propagated in the form of a wave, which meets in its

course another wave starting from a different point of stimulation.

A rapid succession of electrical impulses applied to a muscle produces a persistent, or tetanic, contraction, which is the kind that occurs in the normal physiological action of muscle. The power of the contraction is proportionate to the rapidity with which the stimuli are received. The number of stimuli received by a muscle in a state of powerful contraction is probably about twenty per second, which produces the same number of waves or vibrations in a muscle. These vibrations make a muscle sound, of a pitch corresponding to their rapidity. This can be heard in the temporal and masseter muscles by filling the ears with wax and causing the muscles to contract.

Chemical Composition of Muscle.—Water represents about seventy-five parts per hundred of muscle tissue. Of the remaining 25 parts 15 are proteid; glycogen, fat, and salts (chiefly potassium) constitute the remainder.

When fresh muscles are subjected to pressure, there is forced out a substance, *muscle plasma*, which corresponds to the plasma of blood. The muscle plasma contains a substance, *myosinogen*, analogous to fibrinogen of blood. Coagulation of the muscle plasma produces *myosin*, which is not unlike fibrin in some sespects.

Muscle Fatigue.—A muscle will not contract indefinitely. When it is being artificially stimulated the individual contractions become progressively longer and weaker, until response finally ceases. It is said to be fatigued.

The fatigue results from the consumption of the energy-producing materials at hand, but more particularly from the accumulation of effete products of muscular metabolism—especially of sarcolactic acid.

The seat of fatigue is not, however, in the muscle itself. Nor is it in the supplying motor nerve. It seems that the waste products poison the *nerve terminals* in the end motorial plate,

so that it acts as a block to the passage of an impulse to the muscle. It has also been shown that these same waste products carried to the centers inhibit their power to originate efferent impulses.

Rigor Mortis.—This is a general stiffening of the musculature subsequent to death. Coagulation of the muscle plasma, with the formation of myosin, is the cause of the condition. The muscles become (*a*) shortened and opaque, (*b*) heat is evolved, (*c*) they give off CO_2, and (*d*) become acid in reaction (Kirkes). The acid reaction is due to the presence not only of sarcolactic acid, but of acid phosphates as well.

Rigor mortis usually begins in the neck, and later extends progressively to the muscles of the upper extremities, trunk and lower limbs. It disappears in the order of invasion.

Usually the cause of its disappearance is putrefaction, but in some cases it lasts so short a time that fermentative changes may be responsible.

CHAPTER III.

SECRETION.

Secretion and Excretion.—Ordinarily the product of glandular activity is spoken of as a secretion. On the one hand, glands may take from the blood substances which are preformed in that fluid, which would accumulate and produce detrimental effects if not removed, and which are discharged from the body. On the other hand, glands may form out of materials furnished by the blood substances which are peculiar to that gland's activity, which have an office to perform in the economy, which do not accumulate on removal of the gland, and which are not discharged from the body. The product in the first case is an **excretion,** in the second case a **secretion.** But when it comes to naming an exclusively excretory or an exclusively secretory gland, the task is found to be practically impossible. Probably the most typical excretion of the body is the urine, yet there are in the urine substances, like hippuric acid, etc., which are undoubtedly formed by the kidney, and which do not preëxist in the blood. The succus entericus, *e. g.*, would seem as typical a secretion as it is possible to find, but not infrequently it contains urea when the activity of the kidney is impaired, to say nothing, under normal conditions, of the water and salts which are taken as such from the blood. The liver is notable in its secreto-excrementitious action. While the desirability of thus separating the glands into secretory and excretory and their products into secretions and excretions is granted, the impossibility of such a division is apparent.

It is possible in most cases to apply the distinction to the

separate constituents of the product of a particular gland, but not to the product as a whole. In view of these facts, attention will be given in this chapter to several glands which manifestly produce excretions as well as secretions. The action of the kidney and sweat glands is so predominantly excretory that they are treated separately. In what follows the term "secretion" cannot always be taken as meaning a true secretion, for it is customary and convenient to speak of the "secretion of urine," for example.

Glands.—If we conceive of a single layer of secreting epithelial cells supported by a thin basement membrane, and then this structure invaginated or folded in upon itself, so that the two layers of epithelium face each other with a greater or less interval between them, with the basement membrane constituting the external support for both, we will have in mind the essential structure of a gland proper. The invaginated cells are the **gland cells,** and the interval between the two layers of cells is the **lumen.** Whether the invaginated structure sends off from itself secondary or tertiary folds similar to the original, or whether the lumen of any of these folds is in the shape of a simple tube or sac, or both, is immaterial. They may all be considered as identical in nature with the original invagination and only modifications of its architecture.

However, these modifications are more or less distinguished by names. Those which become complex by numerous branchings of the involuted tube are usually termed **compound,** as opposed to a single **simple** fold; glands are further classified, as **tubular, racemose,** or **tubulo-racemose,** according as the termination of the lumen has the shape of a tube, or sac, or both. Thus a simple or a compound gland may belong to any one of the three last-named varieties. The crypts of Lieberkuhn are simple tubular glands. The glands of Brunner are usually described as compound tubulo-racemose structures.

In a compound gland that portion which communicates with

the surface is called the **duct** and is supposed not to be concerned in actual secretion, but simply in carrying the product away from the secreting terminal ramifications of the subdivisions of the involution—which terminations are called **acini** or **alveoli.** It follows, of course, that a collection of acini may discharge their secretion into the main duct by a smaller duct—that is, that the gland may have various subdivisions of the duct proper.

Furthermore secretions are classified as **external** when they are discharged upon a surface communicating with the external air, such as the alimentary canal, or skin, and **internal** when they are discharged upon surfaces not in communication with the exterior, such as blood-vessels. Both external and internal secretions are liquid or semi-liquid in character, for they must contain water as a vehicle for the salts and organic substances which are present in all of them and which, in fact, distinguish them from one another.

Glands in general have been divided into **serous** and **mucous** by Heidenhain, according as the secreted fluid is watery and thin, or viscid and stringy from the presence of mucin. This division is further warranted by histologic differences in the cells concerned in each kind of secretion. The cells in a serous gland are *small* and *finely granular*, and are in close apposition to each other. Those of mucous glands are *larger*, almost *square* and are definitely separated. Many glands contain both kinds of cells, but since their secretion contains mucin, such glands are usually spoken of as belonging to the mucous variety. It will be seen that the salivary glands illustrate these varieties.

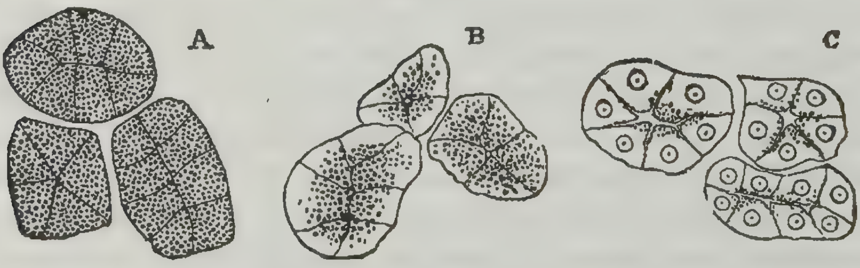
Gland Secretion.—Underneath the basement membrane of a gland (that is, on the side opposite the epithelial cells) ramifies an abundant network of blood and lymph capillaries. This anatomical arrangement favors osmotic transudation from the vessels, especially since the pressure in the vessels is normally greater than in the acini and ducts of the gland. Numerous

experiments, however, prove the inadequacy of simple osmosis to explain all the processes of glandular secretion, especially those connected with the presence of organic constituents; while the undoubted presence of secretory nerves (besides the vaso-motor nerves to the vessels) would seem to give *a priori* evidence that the **glandular epithelium** takes some *active* part in the formation of the secretion. Such an office is granted to these cells, but whether it is of a chemical, or a physical, or a "vital" character is not evident.

(A) Salivary Glands.

The chief salivary glands are three in number on each side of the mouth—the **parotid, submaxillary** and **sublingual.** Besides these, there are, throughout the buccal mucous membrane, a number of smaller glands of similar structure contributing to the formation of saliva. The **parotid** gland is situated just beneath and in front of the lobe of the ear; the **submaxillary** beneath the inferior maxilla about the center of the base of the

FIG. 16.



Cells of the alveoli of a serous or watery salivary gland. (*Brubaker* after *Yeo.*)

A, after rest; *B*, after a short period of activity; *C*, after a prolonged period of activity.

submaxillary triangle, and the **sublingual** beneath the mucous membrane of the mouth, just lateral to the lingual frenum.

The duct from the parotid, **Stenson's duct,** runs beneath the mucous membrane of the cheek to a point opposite the second upper molar tooth, where is its opening into the mouth. The

duct from the submaxillary, **Wharton's duct,** discharges the secretion from that gland into the mouth by the side of the frenum of the tongue. The secretion from the sublingual reaches the mouth by a number of small ducts (**Rivinus**) which open also by the side of the frenum, and sometimes as well by a larger duct, **Bartholin's,** which runs parallel with Wharton's and empties near it.

Histology.—In structure the salivary glands have recently been shown to be of the compound tubular variety, the secreting part being tubular instead of saccular, as was once thought. The parotid is a serous gland, the other two are usually said to be mucous, though they contain both serous and mucous cells.

FIG. 17.

Section of a mucous gland. (*Brubaker* after *Lavdowsky.*)
A, in a state of rest; *B*, after it has been for some time actively secreting.

The ducts subdivide into smaller ducts and tubes, until a distinct tubule is distributed to every acinus and becomes the lumen of that acinus. The whole arrangement resembles the branchings of a tree.

The flow from these glands is greatly increased by mastication. From the parotid the flow is much more abundant on that side upon which mastication takes place. During activity it can be shown that the granules of the serous cells accumulate

towards the lumen of the acinus while the outer segment of the cells becomes comparatively clear. It is supposed that this is an essential step in the production of the organic constituents of the secretion—that the granules contain either the ptyalin or the substance necessary to its formation. It is also supposed that at the same time that ptyalin is being thus produced and discharged, very active constructive changes are occurring in the clear zone of the cells. During activity some at least of the mucous cells seem to break down, but it is probable that the granules in the cell protoplasm become converted into mucin, which, being extruded, seem to destroy the cell itself.

Composition and Properties of Saliva.—While it is possible to draw certain distinctions between the saliva from the different glands, these distinctions are comparatively unimportant, so far as digestion is concerned; for the secretions from the three pairs of glands become mixed in the mouth, and it is their combined effect which, in any particular case, is observed. Saliva contains in 1,000 parts about 994 of water, the remaining six parts being organic and inorganic solids. The organic are mucin, albumin and ptyalin. The mucin possesses a physical value in deglutition. The *ptyalin* is a digestive enzyme and the most important contituent of the secretion. Were it not for the presence of epithelial cells in suspension, saliva would be clear and transparent. Its reaction is *alkaline*, its *specific gravity* is about 1004 to 1008, and the average *amount* of daily secretion is about $2\frac{3}{4}$ pounds.

The parotid saliva is much more watery and mixes much more readily with the food than the submaxillary and sublingual, which latter is mucilaginous and rather gives to the bolus a glairy coating than becomes incorporated in it. The sublingual saliva is thicker and more viscid than the submaxillary.

Nerve Supply.—The connection of the nervous system with salivary secretion deserves particular attention, since the phenomena presented under its influence are typical, and, if not

explanatory of occurrences elsewhere in the body, are at least very suggestive.

Each one of the three glands is supplied with both cerebro-spinal and sympathetic fibers. Each one of them has three kinds of nerve fibers, secretory, vaso-dilator and vaso-constrictor. The secretory and vaso-dilator reach the gland in the cerebro-spinal trunks; the vaso-constrictor in the sympathetic. The vaso-constrictors and vaso-dilators are distributed to the walls of the blood-vessels, and influence secretion indirectly only by increasing or diminishing the amount of blood going to the glands. The secretory fibers exert their influence directly upon the gland cells. It is claimed also that the secretory fibers are divided into sets controlling the production of the energy-yielding constituents and sets controlling the production of water and salts.

The **parotid** gland receives its cerebro-spinal fibers through a branch of the fifth nerve, but when they are traced backward it can be shown that they are in the tympanic branch of the *ninth*, and pass from this branch to the small superficial petrosal nerve and thence to the optic ganglion—from which ganglion they run to the parotid gland by way of the *auriculo-temporal branch* of the third division of the fifth. The cervical *sympathetic* also sends fibers to this gland.

The **submaxillary** and **sublingual** gland are supplied by the same nerves. Their cerebro-spinal fibers leave the brain by way of the facial, follow the *chorda tympani* as far as a short distance beyond its junction with the lingual nerve, and then leave it to reach the submaxillary ganglion and run thence to the submaxillary and sublingual glands. These glands receive *sympathetic* fibers from the superior cervical ganglion.

Influence of Nerve Supply.—Taking the parotid as an example, it is found that stimulation of its cerebro-spinal fibers produces an abundant watery flow of saliva ; the gland becomes decidedly redder, pulsation is sometimes apparent, and it is

evident that the amount of blood is locally increased. When the sympathetic supply of the parotid is stimulated, the secretion is inhibited or reduced to a minimum, the gland becomes pale and the amount of blood in it is evidently diminished.

Similar corresponding results are occasioned in the submaxillary and sublingual glands by stimulation of the chorda tympani and the sympathetic fibers.

It would seem at first, in the light of the vascular changes accompanying stimulation of the two supplies to all these glands, that the resultant phenomena could be explained entirely by variations in the *amount of blood*, and that the nervous system influences their secretion only by contraction and dilatation of the vessels. However, a number of circumstances, which it is unnecessary to relate here, prove that the secretory fibers exert an influence directly upon the cells themselves, causing them to secrete. The mere distribution of these fibers to the gland *cells* presupposes some such function on their part; and it can actually be shown that the secretion can be increased when the blood supply is cut off, or without dilatation of the vessels. Such action, however, is of course only temporary, for the materials for secretion must be supplied by the blood. The exact method of termination of the secretory fibers has not been determined. It is probable that they end between and around the cells and do not penetrate their substance.

Section of the chorda tympani causes a continuous flow of saliva from the submaxillary and sublingual glands for several weeks. This has been termed *paralytic* secretion, and is supposed to be due to the fact that the chorda fibers do not themselves run directly to the glands, but are distributed to sympathetic ganglia (the submaxillary or others in the gland substance). Section of the chorda, then causes, degeneration of its fibers only as for as these ganglia, and their cells are thought to be subject, in some obscure way, to *continuous irritation* during the period for which the paralytic secretion continues.

Afterward the glands atrophy. The same phenomenon in the parotid would doubtless follow section of its cerebro-spinal fibers.

The secretion of saliva is a *reflex act.* The normal stimulus is food in the mouth. The afferent fibers carrying the impressions to the center are in the branches of the *ninth* and the lingual division of the *fifth.* The efferent fibers are those already noticed—and they carry two different but associated kinds of messages, namely, those to the cells causing them to secrete, and those to the vessels, influencing secretion by increasing (or diminishing) the amount of secretory materials by increasing (or diminishing) the amount of blood.

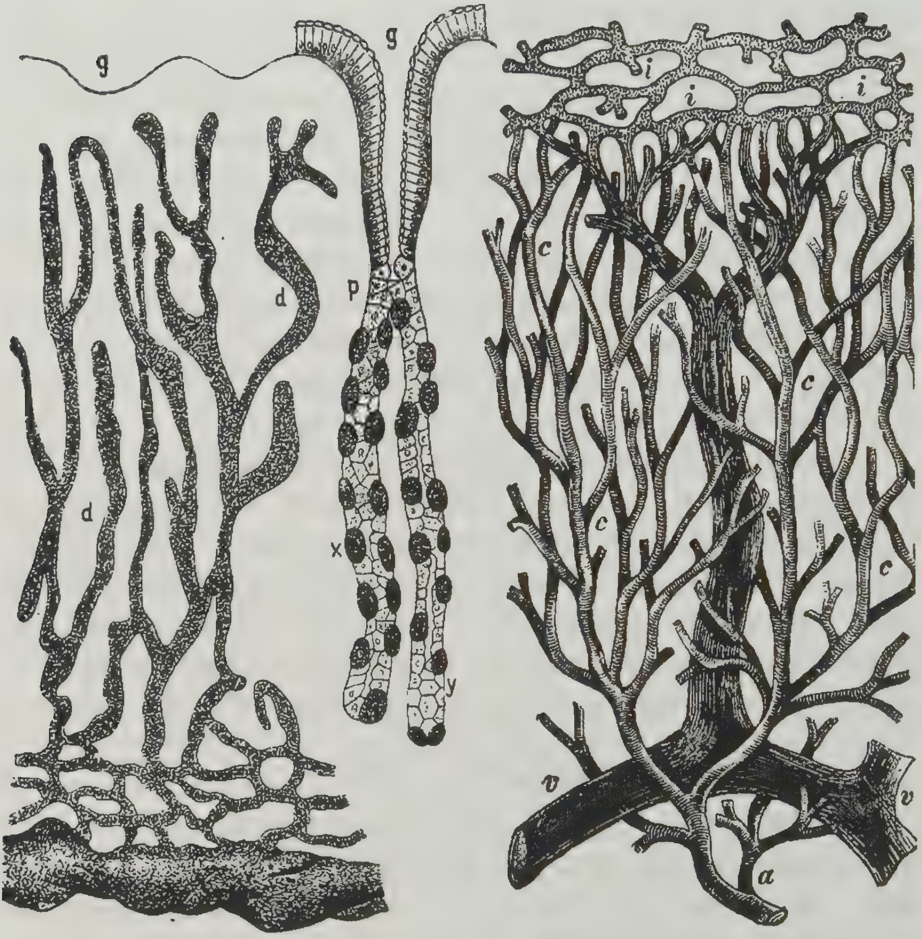
The **center** for this reflex is in the medulla oblongata, close to the origin of several of the cranial nerves. It is a matter of common observation that the salivary flow may be increased by the thought, or sight, or smell of food, or by other impressions, and inhibited by fear, embarrassment, etc. This may be explained by the nearness of the salivary center to the roots of origin of nerves conveying these impressions to the brain.

(B) Gastric Glands.

Varieties.—In the mucous membrane of the stomach are found two kinds of glands. According to their relative *position* with reference to the two ends of the stomach they are called **fundic** and **pyloric.** It is to be noted, however, that neither of these divisions is confined strictly to that portion of the stomach which its name would seem to indicate. According to their *secretion* the glands are called **acid** and **peptic.** The fundic and acid, and the pyloric and peptic are considered to be identical. But attention is called to the fact that while peptic (pyloric) glands secrete *pepsin only*, the acid (fundic) secrete *both acid and pepsin.*

Structure.—Some of the gastric glands are simple tubules, while others may be bifurcated, so that two (or more) tubules communicate with the surface by a single canal. They may all,

FIG. 18.



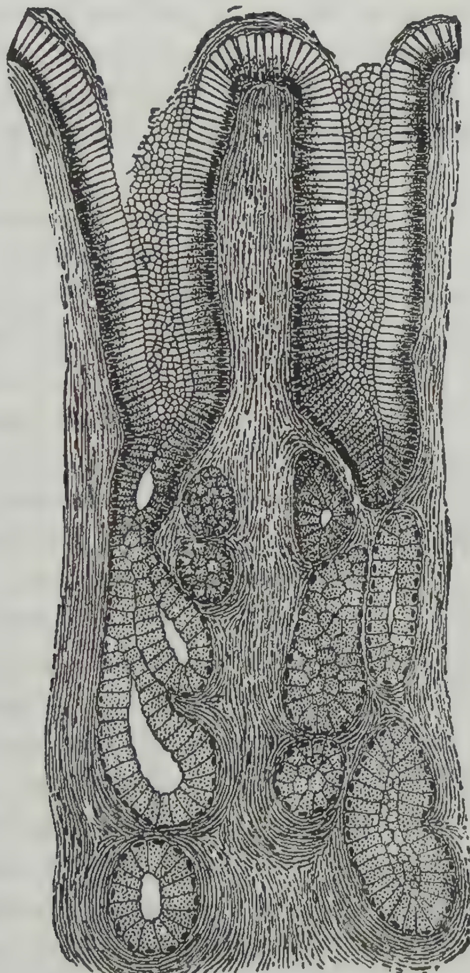
Vertical section of the gastric mucous membrane.

g, *g*, pits on the surface; *p*, neck of a fundus-gland opening into a duct, *g*; *x*, parietal, and *y*, chief cells; *a*, *v*, *c*, artery, vein, capillaries; *d*, *d*, lymphatics, emptying into a large trunk, *e*. (*Landois*.)

however, be classified as belonging to the simple tubular variety. They have a deep secreting portion and a superficial non-secreting portion. The latter is lined by columnar epithelium, and is the duct proper. The former is lined by cuboidal epithelium which discharges its secretion into the lumen, this lumen being only a continuation of the duct. These cuboidal cells are called

peptic cells because they produce pepsin, or its forerunner, **pepsinogen.** The fundic (acid) glands are found to have lying close to the basement membrane a number of large cells at intervals between the cuboidal cells and not extending outward to the

FIG. 19.



Section of the pyloric mucous membrane. (*Landois.*)

central lumen. They are thought to communicate with the lumen by capillary ducts, which may even penetrate their substance. They are supposed to secrete hydrochloric acid,

and are called **acid cells** from this fact, or **parietal cells** from their position. (See Fig. 18.)

Properties and Composition of Gastric Juice.—The secretion of the glands of the stomach is called **gastric juice.** It is thin, colorless, acid in *reaction*, and has a *specific gravity* of about 1005 to 1009. Some 973 parts per thousand consist of water, the remainder of hydrochloric acid and solids in solution. The chief organic constituents are mucin, a proteid, pepsin and rennin. The salts are chiefly the chlorides and phosphates. The *amount* of gastric juice secreted in twenty-four hours is from six to fourteen pounds.

The characteristic and important constituents are **hydrochloric acid, pepsin** and **rennin.** The gastric juice strongly resists putrefaction. The secretion in the pyloric end is said always to be alkaline; that in the fundic always acid. This is accounted for by the distribution of the acid and peptic glands already noted. Except during digestion, the mucous membrane has a neutral or slightly alkaline reaction.

Method of Secretion.—When food is ingested gastric movements very soon begin, carrying the food in this direction or that, as described later. At the same time, the gastric mucous membrane changes from a pale pink to a congested red, and soon drops of gastric juice begin to appear. They run to the dependent portions of the cavity and become incorporated with the alimentary mass. It is believed that if the gastric movements did not occur, this secretion would be limited for fifteen or thirty minutes to a very small area, namely, that with which the food is in contact. But it is comparatively general because the movements bring practically all parts, at least of the fundic mucous membrane, in contact with the food before this time has elapsed. The idea is that up to fifteen or thirty minutes after the introduction of food, the glands are made to secrete by direct *mechanical stimulation* of the food, and after this time the secretion becomes general, whether mechanical irritation becomes general or not.

It ought to be added, however, that in recent years secretion by mechanical stimulation has been denied, and the denial is supported by good evidence. Besides direct proof by experiments, it is shown that this early secretion occurs without mechanical irritation, as when food is chewed and made to pass through an esophageal fistula, or even by the sight of food. These observers (Pawlow) state that food introduced into the stomach through a fistula produces absolutely no flow if the animal experimented upon does not know of the introduction. Under this view the secretion is a distinct *reflex*, the impressions being carried to the center by afferent nerves distributed to the mouth, or by nerves of special sense.

Whether as a reflex or as a result of mechanical stimulation, the fact remains undisputed that the flow begins a few minutes after the introduction of food, and lasts until gastric digestion is completed. After a time it is supposed that *chemical changes* in the food itself further stimulate the gastric glands, through their influence on the secretory nerves. These stimulating chemical products are not developed alike from all foods; and the conclusion is warranted that some substances do not undergo gastric digestion so readily as others. Ordinary bread and the whites of eggs, for example, are said not to develop them. It has been further shown that fats, oils, etc., actually develop substances which chemically *inhibit* gastric secretion. There appears also to be a kind of chemical regulation of the amount and quality of juice, according as much or little, or a varying acidity, is needed in the digestion of the substance in the stomach.

Conditions influencing digestion operate mainly by producing changes in the quantity or quality of *gastric juice*, and these changes in turn are largely effected through the nervous system. Fever, overeating, depressing emotions, strenuous physical or mental exercise, etc., decrease the secretion and correspondingly interfere with digestion.

Changes During Activity.—Like the salivary cells, the cu-

boidal peptic cells can be shown to undergo changes during secretory activity. When at rest they contain abundant granules, but during secretion these granules disappear, first from the base and later from well-nigh the whole cell. The granules are supposed to contain pepsin, or rather *pepsinogen*, for it is thought that pepsin is not formed by the cell directly, but is made out of pepsinogen, which is the product of the peptic cells, probably under the action of hydrochloric acid. The rennin is also supposed to exist in the cells as some preliminary material corresponding to pepsinogen. This material may be termed *rennin zymogen.*

Changes in the acid cells during activity also occur, but are more obscure than those in the peptic cells. The source of hydrochloric acid is a decomposition of the neutral chlorides of the blood and the union of the chlorine thus liberated with hydrogen, but how or why this occurs is not explained by phenomena so far observed.

Secretory Nerves.—While it has been impossible to demonstrate secretory fibers to the cells of the gastric glands, such fibers must exist in the *vagus.* Section of it (and the sympathetic), however, does not entirely stop the secretion, but incidents referred to in a preceding section, such as secretion at sight of food, or when food is chewed and not swallowed, certainly point to an influence of the central system over secretion. Of course the sympathetic fibers to the vessel walls are indirectly concerned.

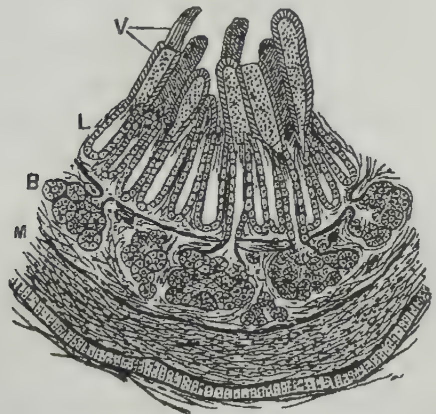
(C) Intestinal Glands.

Besides the *agminate* glands, which are discussed under Digestion and which are probably not true glandular structures, the intestinal glands are those of **Brunner** and the **crypts of Lieberkuhn.** The former exists in the upper duodenum, and are of the compound tubular variety. The latter are set throughout the small and large intestines and are of the typical simple tubular variety.

The **glands of Brunner** resemble the pyloric glands, except

that the number of secondary tubules is much greater. Their secreting cells are similar. The amount of secretion from them is necessarily very small. Whether they produce any digestive enzyme is not known. The **crypts of Lieberkuhn** resemble the pyloric glands, except that they are shorter, seldom bifurcated,

FIG. 20.



Drawing of transverse section of the duodenum,

Showing Brunner's glands, *B*, opening into Lieberkuhn's follicles, *L*; *V*, villi; *M*, muscular coats. (*Yeo.*)

and their secreting cells are columnar in shape. They are supposed to produce almost all the succus entericus, or intestinal juice, which is alkaline in reaction, and contains amylolytic and sugar-splitting ferments.

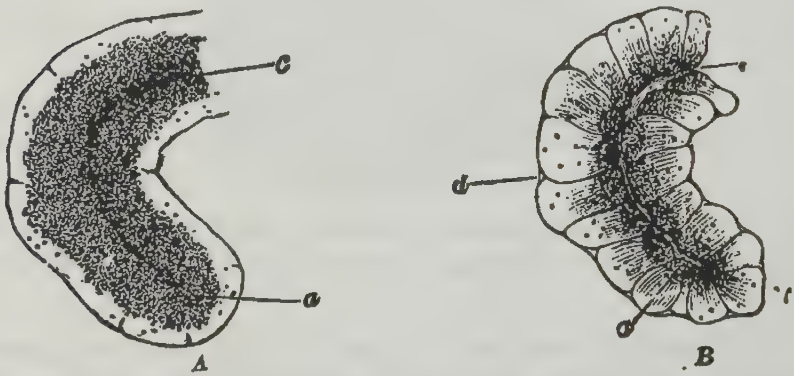
(D) Pancreas.

Anatomy.—The **pancreas** is a large gland lying in the upper part of the abdominal cavity behind the stomach. It has the general shape of a hammer, its head being embraced by the bend of the duodenum and its opposite extremity reaching to the spleen. It weighs some four or five ounces, and is about seven inches long. Its duct, the **duct of Wirsung,** usually joins the common bile duct just where this latter penetrates the wall of the duodenum, so that the bile and pancreatic juice

enter the small intestine together. Sometimes the two ducts do not join, and sometimes a second smaller duct from the pancreas penetrates the duodenum a little below the larger one. The duct of Wirsung traced backward divides and subdivides until its final ramifications end in the **alveoli,** or secreting portions.

Histology.—This is a compound tubular gland. The cells in the alveoli are of the serous type and are granular towards the central lumen. During activity they undergo changes very similar to the salivary cells, the non-granular zone toward the basement membrane increasing and extending and the granular zone

FIG. 21.



One saccule of the pancreas of the rabbit in different states of activity. (From *Brubaker* after *Yeo.*)

A, after a period of rest, in which case the outlines of the cells are indistinct and the inner zone—*i, e.*, the part of the cells (*a*) next the lumen (*c*)—is broad and filled with fine granules. *B*, after the gland has poured out its secretion, when the cell outlines (*d*) are clearer, the granular zone (*a*) is smaller, and the clear outer zone is wider.

becoming correspondingly smaller. Here, as in the salivary glands, it is believed that the granules are made from the clear protoplasm, and contain the enzymes or their formative materials. The formative material in all these glands is given the name of **zymogen,** although the zymogen in a particular gland may have a particular name, as pepsinogen, the forerunner of pepsin, or trypsinogen, the forerunner of trypsin.

Properties and Composition of Pancreatic Juice.—The pancreatic juice is a colorless liquid, alkaline in *reaction*, and has a *specific gravity* of about 1040 if taken from a recent fistula. It coagulates when heated and is prone to putrefaction on exposure. With a specific gravity of about 1040, it contains per thousand some 900 parts water, the remainder being different solid food materials in solution. These constituents are a proteid and three very important digestive ferments, **trypsin, steapsin** and **amylopsin.** The phosphates and carbonates are plentiful and give the fluid its alkaline reaction.

Method of Secretion.—It can be shown that the secretion begins to be discharged into the duodenum very soon after the entrance of food into the stomach, and continues as long as intestinal digestion is in progress. Consequently the flow will be *intermittent* if the meals are far enough apart. It is almost certain that the secretion is a *reflex act* as a result of impressions upon the mucous membrane of either the stomach or the duodenum. The acidity of the gastric juice seems to be the natural stimulus and to exert its influence upon the duodenal mucous membrane. This is not incompatible with the early flow after the ingestion of food, for it will be seen later that at least a small quantity of that food passes quickly to the duodenum and carries gastric juice with it. The composition of the secretion seems to be influenced in some degree by the character of the food. It is interesting that oils increase the pancreatic flow.

Nerve Supply.—The pancreas has, besides vaso-motor fibers to its vessels, distinct secretory fibers, like those of the salivary glands. These fibers probably run in both the sympathetic and the vagus.

Internal Pancreatic Secretion.—Circumstantial evidence leaves scarcely any doubt that the pancreas produces some substance which is discharged into the blood and markedly influences *nutrition*. Removal of the gland is followed by death from inanition in two or three weeks; and previous to that sequel the

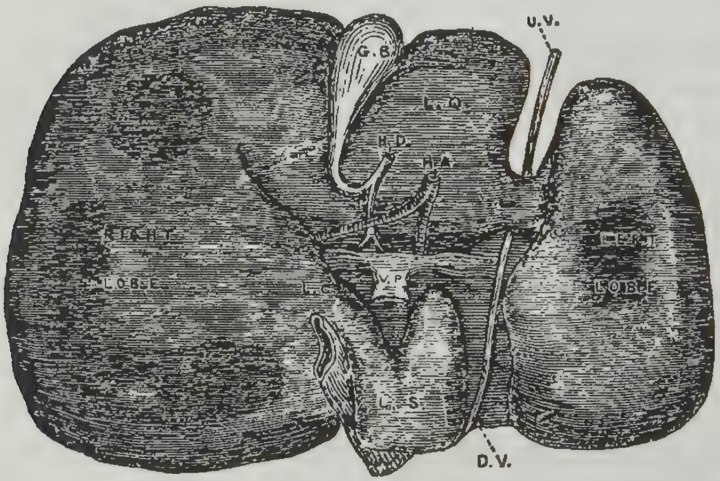
most striking phenomenon is marked glycosuria, with the ordinary symptoms of diabetes mellitus. Retention of a comparatively small portion of the gland obviates this condition. Sugar does not exist normally in the blood, and this internal secretion may contain some ferment which effects its consumption.

(E) Liver.

The liver is the largest gland in the body. Its function is to produce bile, glycogen and urea.

Anatomy.—The liver is situated in the upper part of the abdominal cavity, chiefly in the right hypochondrium. Its weight in the average adult is about four and a half pounds. It is covered,

FIG. 22.



The under surface of the liver.

g. b., gall bladder; *h. d.*, common bile duct; *h. a.*, hepatic artery; *v. p.*, portal vein; *l. q.*, lobulus quadratus; *l. s.*, lobulus spigelii; *l. c.*, lobulus caudatus; *d. v.*, ductus venosus; *u. v.*, umbilical vein. (*Kirkes* after *Noble Smith.*)

except for a small area behind, by peritoneum, processes of which run from it at several points and constitute its supporting ligaments. The proper coat of the liver lies underneath the peritoneum, and at the transverse fissure is continued into the gland as a sheath, embracing the structures entering there and ramify-

ing with them in their distribution. This is the **capsule of Glisson.** It is fibrous in structure, is closely attached to the liver substance, and rather loosely adherent to the structures which it envelops. The walls of the portal vein are seen collapsed on section, while those of the hepatic veins, which are not surrounded by Glisson's capsule, and which are closely adherent to the gland substance, stand well open.

A general idea of the liver's anatomy is obtained by noting that it has *five* lobes, *five* fissures, *five* ligaments and *five* structures passing through the transverse fissure. The *lobes* are right, left, caudate, quadrate and Spigelian. The *fissures* are transverse, umbilical, that for the ductus venosus, the fossa for the vena cava and the fossa vesicalis. The *ligaments* are coronary, right lateral, left lateral, round and suspensory or longitudinal. The *structures* passing through the transverse fissure are the portal vein, the hepatic artery, the hepatic duct, the nerves and the lymphatics.

Blood-vessels.—Of the two blood-vessels entering the fissure the **portal vein** is decidedly the larger. It has collected the blood from the abdominal organs by the radicles of its tributaries, the gastric, splenic, superior and inferior mesenteric veins, while the **hepatic artery** is a branch of the celiac axis. These, having been distributed in a manner to be noted presently, discharge their blood into the radicles of the hepatic veins, which, usually three in number, enter the ascending vena cava, where that vessel passes through the liver behind. Again, it is to be remembered that these two vessels, as well as the nerves and lymphatics, are enveloped in the vagina, or capsule of Glisson.

The portal vein and the hepatic artery give off branches to the capsule of Glisson, constituting the **vaginal plexus.** The portal vein, still ensheathed, then divides and subdivides until its branches run directly between the lobules, and are called **interlobular veins.** These direct subdivisions of the portal vein are not the only interlobular veins, however. Those branches

of this vein which were given off to the capsule of Glisson, having received the corresponding branches from the hepatic artery, also here run between the lobules and make part of the interlobular plexus. The interlobular veins, thus surrounding the lobules and having lobules on either side of them, giving off in both directions branches (lobular branches) which penetrate

FIG. 23.

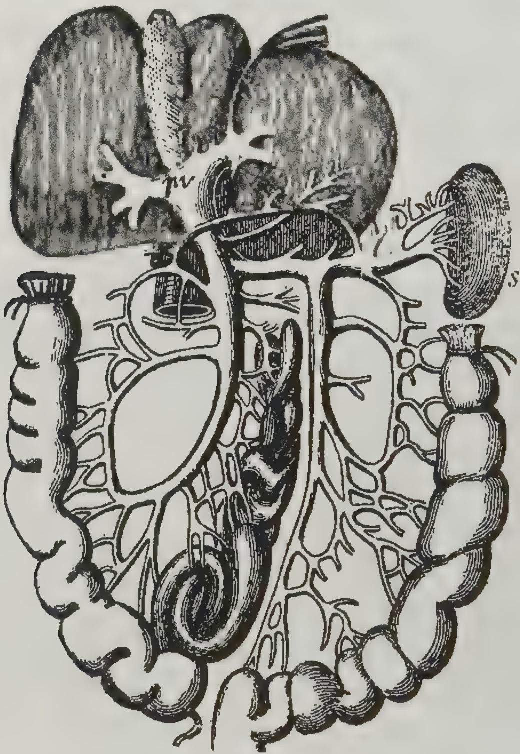


Diagram of the portal vein.

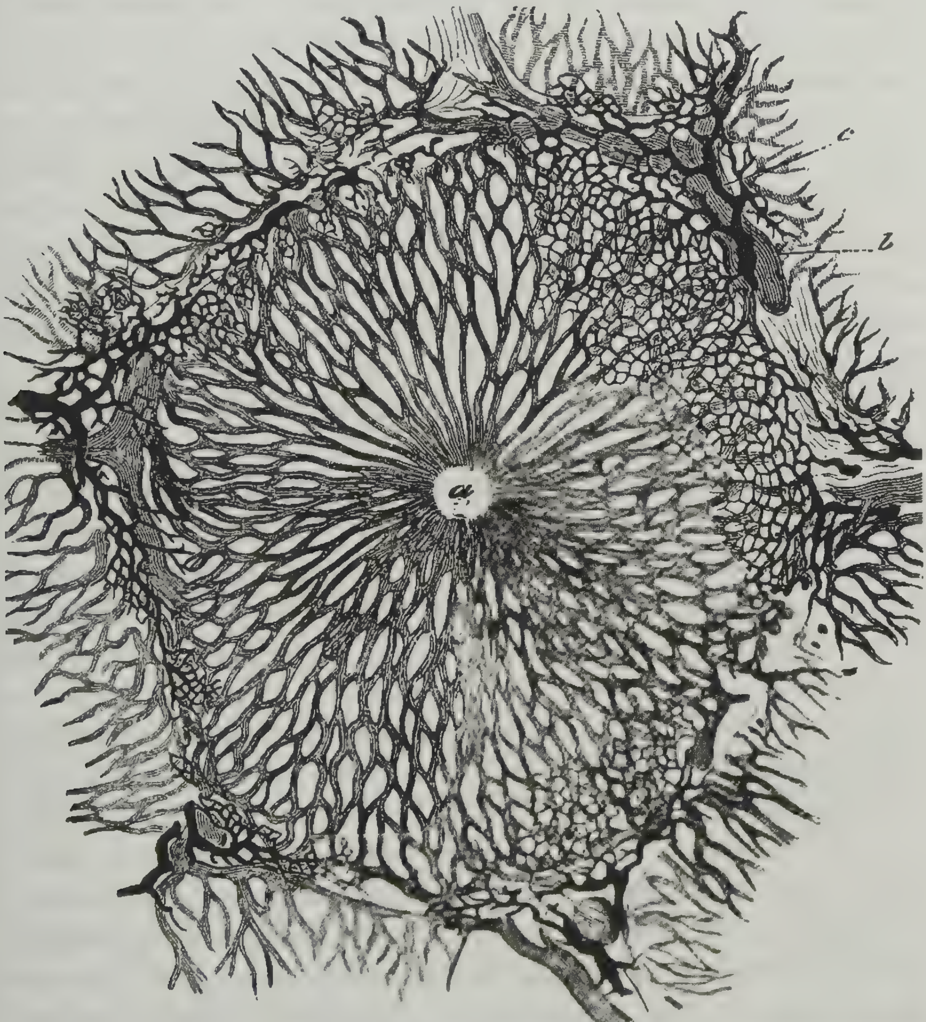
(*pv*) arising in the alimentary tract and spleen (*s*) and carrying the blood from hese organs to the liver. (From *Brubaker* after *Yeo.*)

the lobules, to break up into capillaries. The capillaries finally converge to three or four small radicles, which in turn unite to form a small vein in the center of the lobule. This is the **intralobular vein,** which at the base of the lobule joins the **sub-**

lobular vein. These sublobular veins join each other to form **hepatic veins,** which become larger and larger until they have collected all the blood which has entered the liver. They finally enter the ascending vena cava.

But what has become of the hepatic artery? As soon as it has

FIG. 24.



Section of lobule of liver of rabbit in which the blood capillaries and bile canaliculi have been injected. (From *Yeo* after *Cadiat.*)

a, intralobular vein; *b*, interlobular veins; *c*, biliary canals beginning in fine capillaries.

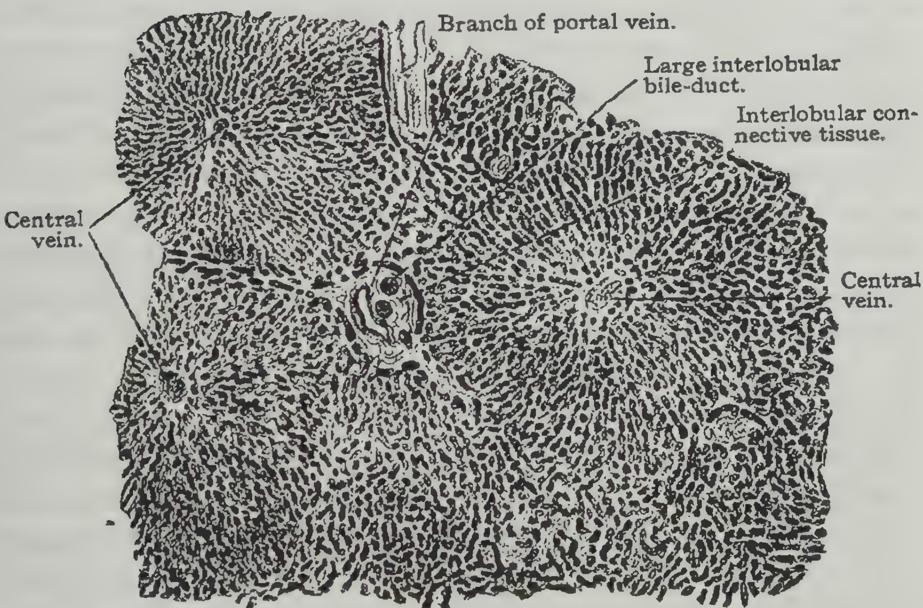
entered the sheath, it gives off branches to the capsule forming part of the vaginal plexus and entering into the vaginal branches of the portal vein just before these run between the lobules. It also furnishes branches to the wall of the portal vein, to the wall of the larger divisions of the artery itself, and to the hepatic duct.

Histology of a Lobule.—The liver is made up of a large number of **lobules** about one-twenty-fifth of an inch in diameter, separated by vessels, nerves and radicles of the hepatic duct. Such a lobule in certain of the lower animals has a distinct polygonal shape, but in man the outlines are not clear. In the lobule are the **hepatic cells,** ovoid in shape, possessed of small granules and one or two nuclei. They are disposed in columns radiating from the central intralobular vein. These cells belong to the epithelial type, and the liver is not essentially different from other glands, such as the salivary, except in the complexity of its arrangement. The analogy is established by the origin of the bile ducts in the lobules between the cells.

Bile Ducts.—It is not difficult to demonstrate the **interlobular ducts,** but to follow them as such into the lobule is less easy. However, there is no doubt at all that they do originate between the hepatic cells. It is probable that here they have no distinct lining membrane, but are mere tubular intercellular spaces, into which the bile is poured and carried into the interlobular duct. Typically a liver cell has one of these bile capillaries on one side and a blood capillary on the other, and while this relation does not always hold good, every cell does communicate with both kinds of capillaries. The interlobular bile ducts consist of epithelium resting upon a very thin basement membrane. As they increase in size they gain fibrous inelastic and elastic tissue, and the largest some non-striated muscular elements. Gradually as the ducts become larger the lining epithelium changes from the columnar to the pavement form. Mucous glands exist in the largest ducts. The interlobular ducts join each other and gradually increase in size as they merge from all

parts of the liver, to leave its substance in two divisions—one from the right and one from the left lobe. These two unite to form the **hepatic duct** which, running a course of about one and a half inches, is joined at an acute angle by the **cystic duct** to form the **common bile duct,** or the **ductus communis choledochus.** This last penetrates obliquely the duodenal wall and discharges

FIG. 25.



From a horizontal section of human liver. × 40.

Three central veins, cut transversely, represent each a center of as many hepatic lobules, that at the periphery are but slightly defined from their neighbors. Below and to the right of the section the lobules are cut obliquely and their boundaries cannot be distinguished. (From *Stohr.*)

the bile into the intestine. The cystic duct has its origin at the apex of the gall bladder, and is about one inch long. The common bile duct has an average length of three inches. (See Fig. 22.)

Gall Bladder.—The **gall bladder** has an oval shape with its large end forward. It is on the under surface of the liver, the

peritoneum running over (or rather under) it. It has a mucous lining and the remainder of its structure is chiefly fibrous. A little plain muscular tissue may exist. Its capacity is about one and a half ounces. Mucous glands are found in its lining, as in that of the large ducts, and these are responsible for the mucin of the bile.

Hepatic Nerves.—With regard to the exact destination of the nerves entering the liver, little is known. Evidence going to establish the termination of fibers in the cells, that is, the existence of distinct *secretory* fibers, is meager. There is little doubt that secretory fibers for the *glycogenic* function of the liver do exist. It is known that fibers from the vagus, phrenic and solar plexus enter the fissure, but they cannot be followed farther than the ramifications of Glisson's capsule between the lobules. Of course, vaso-motor fibers go to the vessels, as elsewhere. Fibers acting similarly go also to the muscular tissue of the large ducts and of the gall bladder. The contraction of the gall bladder is thought to be reflex, afferent impressions being conveyed by the vagus from the mucous membrane of the duodenum.

Hepatic Lymphatics.—The lymphatics are abundant, and those not originating in the connective tissue are thought to originate by perivascular canals surrounding the blood-vessels of the lobules. The fact that when the outflow of bile is occluded it passes, not into the vascular, but into the lymphatic circulation is a curious circumstance. It may be due to the absence of a definite wall for the intralobular ducts and their comparatively free communication with the lymphatics in those localities.

Properties and Composition of Bile.—Human bile is of a dark greenish-red color, has a bitter taste and is practically odorless when fresh. It undergoes putrefaction easily, but is not coagulable by heat. It is viscid, chiefly on account of the mucin it contains. It has an alkaline *reaction*, and a *specific gravity* of about 1030. Besides water, which constitutes more than

ninety per cent. of its bulk, it contains the sodium salts of taurocholic acid and glycocholic acid (the biliary salts), cholesterin, bilirubin, lecithin, fats, soaps, mucin and various inorganic salts, such as sulphates, carbonates, phosphates, etc., and a quantity of carbon dioxide. The quantity of bile secreted in twenty-four hours is about two and a half pounds.

In human bile **sodium taurocholate** largely predominates over **glycocholate.** These are formed as acids by the liver cells, are absorbed in their passage down the intestine, and are presumably *those parts of the bile which are concerned in its digestive action,* particularly in the absorption of fats. So far as these constituents are concerned, the bile is a typical *secretion.*

Cholesterin, on the other hand, seems to be simply removed from the blood by the liver cells, and is discharged in the feces, where, however, it exists in a slightly changed form, **stercorin.** It is thought to be held in solution by the bile acids, glycocholic and taurocholic. So far as this constituent is concerned, therefore, the bile is a typical *excretion.* It is produced in many of the body tissues, and no function has been discovered for it.

Bilirubin is the characteristic coloring matter of the human bile; that of herbivorous animals is biliverdin, and a little of this latter is also present in human bile. These pigments originate from hemoglobin. It is supposed that when the red corpuscles break down, "the hemoglobin is brought to the liver, and then under the influence of the liver cells is converted into an iron-free compound, bilirubin or biliverdin." (Howell.)

The **lecithin** is probably an end product of physiological activity in the tissues, and is apparently an excretion.

The **mucin** gives the fluid its viscid character.

The production of bile is continuous, but this does not mean that its discharge into the duodenum is continuous, for in the intervals of digestion it is not admitted (freely at least) into the intestine, but regurgitates from the ductus communis choledochus through the cystic duct into the gall bladder, which acts as a

reservoir until its contents are needed. The secretion is more active, however, during intestinal digestion than at other times. This appears to be reflex, but may be simply a result of the increased amount of blood passing through the portal vein to the liver during that period, for the whole alimentary canal is congested while digestive activity is in progress. Again, it is known that the best cholagogue is bile itself, and some of the bile is absorbed in its passage down the intestine. Its presence in the blood may account for the accelerated flow.

Method of Secretion and Discharge.—The bile is a product of the liver cells. How they receive their normal stimulus is obscure. But it is reasonable to suppose that a larger supply of blood means a more abundant secretion. Such an increase of blood supply occurs during digestion.

The cells discharge the bile into the bile capillaries, which pass it onward either to the intestine directly, or, during the intervals of digestion, to the gall bladder. When food enters the duodenum, a reflex influence causes the wall of the gall bladder to contract and compress its contents. The only outlet is through the cystic duct into the common duct, and thence into the duodenum. This reflex does not take place until food has entered the duodenum, and of different foods it is found that proteids (peptones) and fats are the most efficient stimuli.

The secretion of bile is not stopped by ligation of either the portal vein or the hepatic artery, showing that both of these vessels contain bile materials. But it would be unreasonable to suppose that the blood of the portal vein does not furnish the bulk of secreting material.

The function of bile will be referred to under Digestion.

Glycogenic Function.—The formation of **glycogen** is connected with nutrition, but will receive some notice here. This is an *internal* secretion. It is produced by the liver cells, and can be demonstrated in their substance by the microscope and by chemical reagents. It can also be shown to increase markedly

after eating. and to decrease notably when eating is refrained from for some time.

Glycogen is a carbohydrate very similar to starch, and when ingested it is acted upon by the same enzymes and undergoes the same conversions. Furthermore, the amount of glycogen in the liver is very greatly increased by restricting the diet to carbohydrate foods and is lessened considerably below the normal (that is, its amount on a mixed diet), but is not reduced to zero, when proteids alone are taken. This points to the conclusion that the source of glycogen is **carbohydrates,** but that it can be formed to some extent from proteids. Let it be said now that practically all carbohydrates are converted by digestion into *maltose*, or *maltose* and *dextrin* and furthermore that *during absorption* these sugars are converted into *dextrose* or *dextrose* and *levulose*. It is customary to assume that the digestion of a carbohydrate means its conversion into dextrose (glucose, levulose). It is, then, this sugar which is carried to the liver by the portal vein.

We may say that the formula for dextrose is $C_6H_{12}O_6$ and for glycogen $C_6H_{10}O_5$, though neither of these formulæ is probably exactly correct. It will be seen, therefore, that the abstraction of one molecule of water (H_2O) from dextrose will produce glycogen, and this is the change which the liver cells are supposed to effect. Again, when the conversion of dextrose into glycogen has taken place, the glycogen is *stored up in the liver cells*, to be given off continuously to the blood only in such quantities as the system may demand. The liver thus becomes a warehouse for the storage of all the carbohydrates.

It will be seen under Nutrition that the carbohydrates furnish the chief material to be burned up in the body for the purpose of liberating heat and furnishing energy, and if they should be consumed as soon as they enter the circulation, there would be not only an unnecessary waste during their quick consumption, but also an unfortunate lack of energy-producing materials before

another meal. This storing up brings about a kind of conservation of energy and an economical regulation of its distribution. The amount of sugar in the circulation at any time is very small, and a single carbohydrate meal may, by the action of the liver, be made to supply the carbohydrate demands of the tissues for a considerable period.

Now, it was just said that the sugar of the blood is dextrose; if the dextrose of the portal blood is converted into glycogen to be stored up, it must be *reconverted into dextrose* before it can leave the liver, since it leaves by the blood. The cells do effect the second conversion, and this is the second part of the glycogenic function. It may be that the liver cells produce an enzyme corresponding to ptyalin, which converts the glycogen. Dextrose does not normally exist in the liver cells. At the very moment of its formation it is carried away by the blood.

The fact that the liver can form glycogen out of proteids shows, of course, that the nitrogen is eliminated from the proteid molecule in some way. A carbohydrate molecule is left to be oxidized in the usual manner. This is thought to be the initial step in the final consumption of proteids in nutrition. The fats have no influence on glycogen formation.

Glycogen also exists in other parts of the body, particularly in the voluntary muscular substance. The cells of the tissue in which it is found must also have a glycogenic function.

Urea Formation.—But the liver has another function besides the production of bile and glycogen, and that is to form **urea.** It will be seen later that the chief end product of proteid metabolism is urea, and that it is eliminated almost entirely by the kidneys. The liver is much more active in the production of this substance when the portal blood is charged with digested materials, but it also forms urea in fasting animals. The liver must, therefore, be capable of forming urea from some of the products of digested foods. With reference to its formation in fasting animals, suffice it to say here that it seems that as long as

proteid metabolism goes on in other tissues, there are produced in those tissues materials (ammonia compounds) which, when carried to the liver, are converted by it into urea. Further notice will be given to this phase of the subject under Nutrition.

The liver cells produce urea; it enters the blood, is carried to the kidneys and eliminated by those organs. In the mechanism of its production and discharge from the liver, it thus corresponds to the internal secretions, though urea is distinctly an *excretion.*

It must not be supposed, however, that the liver is the only organ producing urea. There are other organs which certainly produce it, while there are those who maintain that it is produced directly wherever proteid metabolism is in progress.

(F) Sebaceous Glands.

The **sebaceous glands** (see Hair-follicles) are chiefly associated with hair-follicles and, existing wherever hair is to be found, cover well-nigh the whole cutaneous surface. They are of the simple or compound tubular type, and discharge their secretion into the hair-follicle near its outer extremity. The alveoli are lined by several layers of cuboidal epithelial cells. The cells of the layer nearest the lumen contain fatty matter, and are thought to form the secretion by breaking down and being thrown off themselves. Their place is taken by cells from the deeper layers, which undergo similar changes and disintegrate.

Composition and Properties of Sebum.—Chemically sebum is largely made up of fatty matters. It also contains cholesterin, which is in combination with a fatty acid. It forms a thin coating over the cutaneous surface, accounting for the normal oiliness of the skin. It also contributes to the characteristic softness of the hairs, and prevents their breaking off from brittleness. Its presence over the body surface may have some influence in regulating the loss of heat by evaporation.

Cerumen, smegma and the secretion from the **Nabothian**

glands are only modified forms of sebum, and the structures producing these secretions belong to the class of sebaceous glands.

(G) Mammary Glands.

Structure.—The **mammary glands** are two in number in the human being, and are loosely attached to the great pectoral muscles. They are rudimentary in both sexes until puberty, and in men throughout life. At puberty the gland in the female enlarges markedly, but is never fully developed before pregnancy. At this time the gland vesicles make their appearance, and the rudimentary ducts come to be more and more ramified. These ramifications do not reach their full development, however, until lactation begins. The skin covering the areola of the nipple is dark, especially during pregnancy, and much thinner than over other parts. The dark color is due to a deposit of pigment.

The mammary gland belongs to the compound tubulo-racemose type, and consists of fifteen or twenty **lobes** bound together by areolar connective tissue. Each lobe is made up of a number of **lobules,** containing the **alveoli** or secreting portions. The secretion from all the alveoli and lobules of a lobe converges to a single duct, which discharges its contents upon the surface of the nipple without anastomosis with any duct. There are, therefore, some fifteen or twenty ducts thus opening upon the surface. Each of them has a dilatation beneath the nipple, and it is in these sinuses largely that the milk accumulates during lactation. When lactation has ceased the ducts retract, the sinuses disappear, the alveoli undergo retrograde changes, and the whole gland is inclined to become flabby and pendulous. It does not regain after pregnancy the firmness which characterized it before.

Secretion of Milk.—After parturition the first discharge from the gland is **colostrum,** a liquid resembling milk in some respects. In two or three days the true milk appears. Besides

water and salts, all the constituents of milk are formed by the cells of the mammary gland. During the period of gestation the cells lining the alveoli are flat and have only a single nucleus. When they begin to secrete they increase in height, the nuclei divide and that portion of the cell toward the lumen undergoes fatty degeneration. This fatty material is extruded into the lumen and apparently constitutes a part of the secretion. The liquid constituents taken out of the blood probably hold the proteid and carbohydrate portions in solution, while the fatty particles constitute the fat of the milk. Thus secreted, the liquid accumulates in the ducts and sinuses until removed by the infant or otherwise. The fact that the secretion of milk in woman is influenced by emotions of fear, grief, etc., is strong evidence of a nervous control of the procedure, but proof of secretory fibers to the cells has not been established.

The quantity of food required by the mother during the time the child is nursed is increased, but no particular kind of food seems to be especially required. The larger demand for liquids is marked, however, and when the quantity of milk is increased by a large ingestion of liquids, the solids in the secretion are not relatively diminished.

Composition and Properties of Milk.—Human milk has a specific gravity of about 1030, and is not so white or so opaque as cow's milk. Besides water, its chief constituents are fats, lecithin, cholesterin, casein and lactose, of which the two last named are the most important. *Casein* is the main proteid constituent. *Lactose* is very abundant, and is responsible for the sweet taste and for a large part of the nutritive value of the fluid.

(H) Thyroid Gland.

The **thyroid gland** consists of two glandular masses united by an isthmus of the same structure. It lies in front of the trachea at the lower end of the larynx. It consists of a large number of vesicles bound together by connective tissue. Each vesicle

is lined by cuboidal epithelial cells, which secrete a semi-gelatinous substance, **colloid.**

It has long been known that the removal of the whole thyroid gland, including the parathyroid, occasioned marked interference with nutrition and other changes, the chief of which are disturbances of muscular coördination, possibly convulsions, emaciation, apathy, and subsequent death. There is no duct connected with the gland, and the secretion is therefore an *internal* one. Very little is known of it except that it is necessary to the maintenance of life. If a very little of the gland be left, or if, after its complete removal, a small bit of it be transplanted in some other part of the body, or if the animal be fed on the thyroid extract or the fresh gland, the characteristic symptoms do not ensue.

The muscular disturbances direct the attention to the central nervous system when an attempt is made to explain the occurrences, and it is not improbable that the effect of the thyroid secretion is in some way exerted upon or through the central system. It seems generally agreed that the thyroid does discharge a secretion into the blood and that it is the withdrawal of some part of that secretion from the circulation which is responsible for the remarkable train of symptoms sequent upon its removal. This essential constituent is regarded by some as being an agent which destroys certain toxic principles in the blood, by others as being requisite to the metabolic functions in the body without destroying anything. Baumann has isolated from the gland substance a material containing a large proportion of iodine, to which he gives the name **iodothyrin,** and it is very probable that this is one, at least of the beneficial substances in the thyroid secretion.

(I) Adrenal Glands.

The **adrenal gland** or **suprarenal capsules,** resting upon the upper ends of the kidneys, are ductless glands whose removal is

followed by weakness, impaired nutrition and disturbances in the circulation. Death usually supervenes in two to four days. These bodies must produce an internal secretion which is removed by way of the adrenal veins. It may destroy toxic substances in the blood. A solution injected into the circulation certainly affects the middle wall of the vessels, causing contraction, and a heightened pressure. The heart is also notably inhibited. It is not thought that the effect on the vessels is brought about through the vaso-motor nerves, but by direct excitation of the muscular substance. Little in fact is known about the secretion, except that it is necessary to life. Abel has isolated an alkaloid, **epinephrine,** which is claimed to be the active principle. These glands are the seat of lesions in Addison's disease, and many cases of this malady are at least favorably influenced by the use of adrenal extract.

(J) Pituitary Body.

The **pituitary body** lying in the sella turcica on the superior surface of the sphenoid bone, also produces an internal secretion of physiological value. Its removal is regarded as causing death. Howell has shown that injection of extract from the posterior division occasions a rise of temperature and slowing of the heart. Its situation makes satisfactory experiments very difficult.

(K) Testis and Ovary.

The **testes** and **ovaries,** though not probably true glands, also may produce an internal secretion of obscure physiological value. It is not essential to life. Injections of extracts from these bodies are claimed to have a remarkable stimulating effect upon the nervous and muscular systems. In mental and physical disturbances occasionally following removal of the ovaries, gynecologists often find administration of the ovarian extract to be beneficial.

CHAPTER IV.

THE BLOOD.

General Characteristics.—The blood is a red, opaque fluid having a characteristic stale odor, a salty taste, and classed as a connective tissue. It has its specific gravity varying from 1053 to 1066. In woman it is 1053 to 1061; in man, 1057 to 1066. Anything that will cause the metabolic processes or the physiological combustion to increase or decrease will increase or decrease the specific gravity.

The reaction of the blood is neutral. The nature of the diet, either meat or vegetable, causes this neutrality to turn to either an acid or an alkaline reaction.

The blood temperature is that of the body. In the periphery it is about 99° F.; in deeper vessels it varies from 100° F. to 107° F.; and in the hepatic veins it is about 107° F.

The Function of the Blood.—The most important of the physiological functions of the blood is twofold:—First, to carry food material resulting from digestion and oxygen from the lungs, to the lymph current for cell appropriation; and second, to remove refuse from the tissues by carrying to the excretory organs the products of katabolism or the waste resulting from physiological combustion. Besides the two functions just given, the blood carries the internal secretions from one part of the body to another, equalizes the body temperature, and protects the tissues from invasion by hurtful microörganisms.

Quantity and Distribution of the Blood.—The quantity of the blood in the body is estimated at about 7.5 per cent. of body

weight. A man weighing 150 pounds has a fraction over eleven pounds of blood, which is about one-twelfth of the body weight.

The distribution is generally given as, one-fourth in the heart, large arteries, lungs, and veins; one-fourth in the liver; one-fourth in the muscles attached to the skeleton; and the other one-fourth variously distributed to the other organs of the body.

Composition of Blood.

The blood is composed of Plasma, and (2) Corpuscles.

(1) Plasma.

Let uncoagulated blood stand at a low temperature and the corpuscular element will sink to the bottom, leaving superimposed a clear, straw-colored fluid. This is the plasma. Plasma is the blood minus the blood corpuscles and forms about 65 per cent. volume of the blood. It is a yellowish fluid with specific gravity of 1003 and contains about 9 per cent. of solid matter. The solid materials are:—

(a) Proteids

1.—Fibrinogen (fibrin)

2.—Serum globulin

3.—Serum albumen.

(b) Refuse resulting from physiological combustion; as urea, lactic acid, etc.

(c) Carbohydrates, as grape-sugar.

(d) Salts, chiefly sodium chloride; small quantities of acid calcium carbonate, and magnesium sulphate.

Proteid Element of Plasma.

This constituent of the plasma is of marked importance, because coagulation or clotting results from the changes that take place in it.

Coagulation.—There is confined in the white corpuscles of the blood in some unknown combination an unformed ferment

known as **Thromin.** This element is inactive in vessels that are intact, and some injury has to happen to the element containing it before it is actively set free; and it cannot act except in the presence of a soluble calcium salt. When **thrombin** is set free the proteid fibrinogen is converted into an insoluble substance called **fibrin.** This fibrin ensnares the corpuscular element in its meshes and contracts into a hard mass called a clot. The clear fluid portion that remains after the clot is formed is called serum, which is really plasma minus its fibrin. So we see that plasma is serum plus fibrin.

The liberation of the thrombin may result from injury coming from the exterior, as a cut vessel; or from foreign agents present in the blood, as when bacteria cause phlegmasia alba dolens or "milk leg." In either event the element containing the thrombin is caused to disintegrate.

Blood is kept from coagulating by (1) intact vessels walls, (2) low temperature, (3) addition of saturated salt solutions, (4) by addition of salts of oxalic, hydro-fluoric and fatty acids, and (5) by injection of proteosis and leech extractions.

Importance of Coagulation.—If it were not for coagulation the slightest injury would entail the loss of an immense quantity of blood. The clotting causes hemorrhage to cease, unless the vessel cut is so large that the volume of the flowing blood prevents the formation of a clot. There are individuals devoid of the fibrin-forming power and the least abrasion means serious hemorrhage. These are called **Hemophilia** or "bleeders."

The following table gives, in a concise form, the elements of the blood and shows their relation in coagulation:

Blood	Plasma	1.—Serum		
		2.—Fibrinogen	(a) Serum albumen	
			(b) Serum globulin	
			(c) Fibrin	Clot
	Formed Element—Corpuscles		Red	
			White	
			Platelets.	

Immunity.—In the serum of the blood is developed certain substances possessing the ability to kill bacteria and foreign cells generally. If an individual successfully combats a disease due to poisons from pathogenic bacteria, the serum of his blood is rendered antagonistic to the action of these bacteria and the disease cannot gain foothold again. In the same way animals are inoculated with disease and the serum from these animals injected into a person suffering from the same disease. The antagonistic quality in the animal serum destroys or counteracts the poisonous quality in the person.

These antagonistic agencies in the blood serum are **alexins** and **antitoxins.** They differ in that **alexins** destroy the pathogenic organisms themselves, while antitoxins simply counteract the effects of the poisonous products formed by the pathogenic organisms.

(2) Corpuscles.

Floating in the plasma of the blood we have a cellular formed element moving and functionating. This element is the corpuscular element and is composed of (a) the red blood corpuscles, (b) the white blood corpuscles, (c) the blood platelets. The corpuscles form about 35 per cent. of the volume of the blood.

(a) Red Blood Corpuscles.

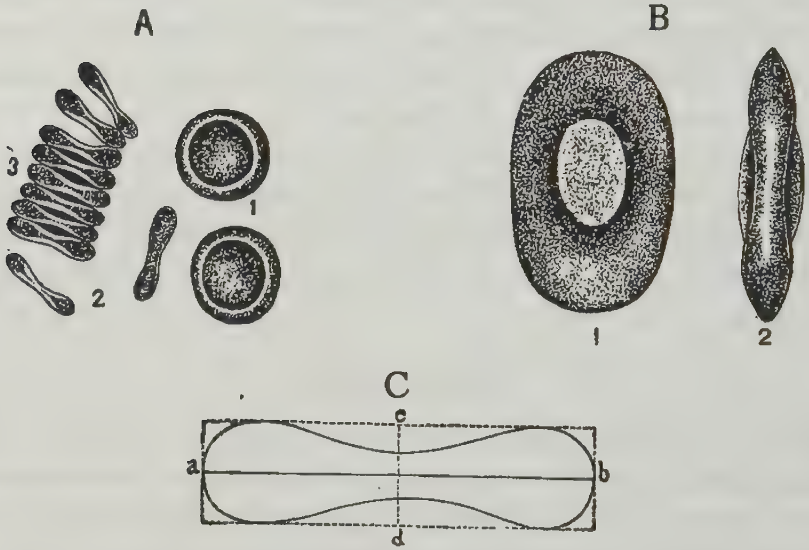
General Description.—The red blood corpuscles are circular, bi-concave discs with rounded edges. They are from 7 to 8 microns in diameter and 2 microns in thickness, so can only be viewed under the microscope. Looked at singly they give a yellowish-green color, collectively they are red.

Number.—In males there are about 5,000,000 red blood corpuscles to a cubic millimeter; in females about 4,500,000. The proportion of red corpuscles to white is one white to every 500 red.

Origin and Destruction.—The red corpuscles are continu-

ously being destroyed in the body and it appears that this destruction occurs principally in the liver. As the red cells are thus destroyed it is natural to look for a place of manufacture. In the embryo we find that this generation takes place in the liver and in the spleen; in the adult it seems that the manufacture takes place only in the red marrow of the bones.

FIG. 26.



A, human colored blood corpuscles—1, on the flat; 2, on edge; 3, rouleau of colored corpuscles. B, amphibian colored blood corpuscles—1, on the flat; 2, on edge. C, ideal transverse section of a human colored blood-corpuscle magnified 5,000 times linear—a, b, diameter; c, d, thickness. (*Landois.*)

The red corpuscles are formed from colored, nucleated cells called **hemoblasts.**

Constituents of Red Blood Corpuscles.—The red blood corpuscles are made up of 65 per cent. water and 35 per cent. solid. The principal solid constituents are (a) hemoglobin (oxyhemoglobin) 87–95 per cent.; (b) stroma, composed of fat, lecithin, and cholesterin; (c) and salts, principally potassium chloride, and potassium phosphate.

Hemoglobin.—Hemoglobin is the coloring matter of the

blood, and is composed of (1) hematin, the pigment containing iron; and (2) globin, a proteid. Hemoglobin is of great physiological importance, because of its ability to unite with oxygen and form oxyhemoglobin. By it the blood carries its oxygen from the lungs. It also unites to some extent with carbon dioxide and it is by its means too that carbon dioxide is brought from the tissues. We find oxyhemoglobin chiefly in the arterial blood, while in venous blood we find both hemoglobin and oxyhemoglobin. In asphyxiated blood we find only hemoglobin.

The **stroma** is the colorless framework of the corpuscles after the coloring matter is dissolved out. The hemoglobin is ensnared in the stroma.

(b) White Blood Corpuscles.

General Description.—The white blood corpuscles or **leucocytes** are large, colorless, nucleated cells with no general form, but capable of distortion by ameboid movement.

Number and Origin.—According to their size and the proportion of nuclei to protoplasm we have several kinds of leucocytes, but they are all white corpuscles and of the same general structure. They number one to five hundred as compared with the red, or ten thousand in one cubic millimeter. They are formed in the spleen and lymphatic glands.

Function.—The white corpuscles are not under the control of the central nervous system, but are controlled by some chemotaxic force. They are able to go and come by ameboid movement through the stromata of capillary walls and wander here and there in the tissues. It is this that gives them their name of **wandering cells.**

White blood corpuscles are of importance from a physiological standpoint, because of this ability to wander. They can transfer undissolved substances from one part of the body to another and can destroy and remove foreign substances and hurtful microörganisms.

The power they have of ingesting foreign substances is called **phagocytosis.** They will migrate in large numbers and surround a foreign object and endeavor to remove it from the tissue. They have the power of liquefying tissue and it is this liquefied tissue mixed with the dead bodies of white corpuscles that is known as pus.

(3) Blood Platelets.

These are colorless discs about one-third to one-fourth the size of red blood corpuscles. Some claim for them the full value of blood cells, while some claim they are the nuclear remains of destroyed leucocytes. They are about 635,000 to one cubic millimeter of blood. As to their function little is known. Some claim they play an important part in the coagulation of the blood. Nothing definite is known of their origin.

CHAPTER V.

THE CIRCULATION OF THE BLOOD.

General.—We have seen that the composition of the blood fits it for its function of carrying food stuffs to the tissues and removing the products of combustion; but, for the blood to exercise these offices, it is necessary that it be in communication with the outside world and the tissues. The movement it makes through its network of vessels in order to carry products from the exterior to the interior and from the interior to the exterior is what is meant by circulation.

Pulmonary and Systemic Circulation.—Two systems of circulation are generally distinguished. The first is the **pulmonary,** and is the circulation of the blood through the lungs in order to get rid of carbon dioxide and to get a fresh supply of oxygen by aeration. The second is the **systemic** and is the circulation through the great masses of body tissue in order, by means of the lymph, to supply the tissues with different solid, liquid, and gaseous nutritive material and take from the tissues the products no longer needed but which must be eliminated. These systems are also called respectively the lesser and greater circulation.

Discovery.—The circulation of the blood was an unknown fact up to 1628 when the discovery of its movements was made and proved by Sir William Harvey, an English physician prominent in his time and now famous for this discovery.

The Circulatory Apparatus.—The blood circulates through a series of structures known as blood-vessels, which divide up, ramify, and go to all parts of the body. These vary from large, ma-

croscopical vessels to tiny, little, hair-like tubes that cannot be seen with the naked eye.

The central and large portion of the circulatory vessels is the **heart.** From this leads off the **arteries,** these in turn connect with the **capillaries,** and these with the **veins,** which lead back to the heart.

I. THE HEART.

The heart is a hollow, muscular organ divided by a muscular septum into two distinct compartments designated for convenience, the right and left heart. The right side, and similarly the left, is divided by a muscular septum into two chambers, the upper called the auricle and the lower the ventricle. There is an opening between the right auricle and the right ventricle and one between the left auricle and the left ventricle and each opening is guarded and can be closed by a thin membranous flap called a valve.

Situation.—The heart is located in the thoracic cavity behind the sternum. It is placed in a diagonal position and its base is in the middle line and looks backward, upward, and to the right. Its apex is three inches to the left of the median line, a half inch internal to the nipple, and in the fifth intercostal space.

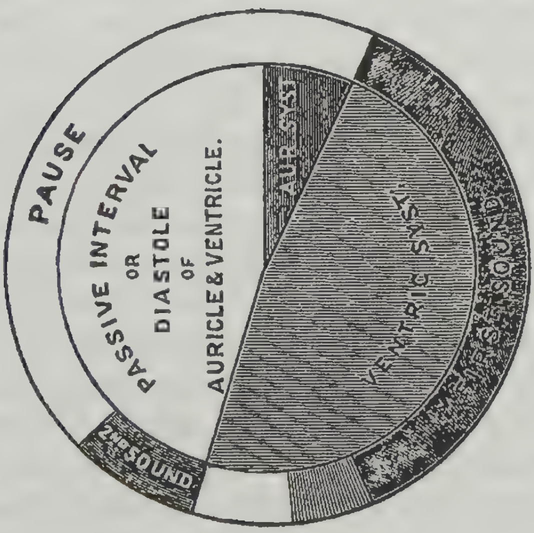
Covering and Lining.—A serous sac, called the **pericardium,** covers the heart. It hugs the muscle of the heart closely, completely enveloping the organ, then turns back on itself leaving a space between the outer layer and the layer next to the muscle. In this space is a fluid which acts as a lubricant.

The heart is lined by a membrane called the **endocardium,** which is composed of epithelium.

Structure.—The muscle of the heart is striated, but contrary to the usual rule is involuntary in its action. The muscle fibers run circularly, obliquely, and some in the form of the figure eight, thus giving the power to contract and squeeze the blood on into the circulation.

Contraction.—The physiological contraction of the cardiac muscle is called **systole,** the relaxation is called **diastole.** The contraction of the heart starts at the mouth of the veins and, with a uniform rhythm glides along through the auricles and along to the ventricles, each part relaxing as the rhythmic contraction passes on. The whole time of contraction, from one

FIG. 27.



Scheme of cardiac cycle.

The inner circle shows the events which occur within the heart; the outer the relation of the sounds and pauses to these events. (*Kirkes* after *Sharpey* and *Gairdner.*)

beginning in the vein to another beginning, is called the **cardiac cycle.** It lasts about .86 second.

The **cycle** may be divided thus; the auricles contract (systole) and ventricles are relaxed (diastole) which occupies .16 second; the ventricles contract (systole) and the auricles are relaxed (diastole) and this occupies .3 second; both auricles and ventricles then rest and this occupies .4 second.

Number of Beats.—In an adult the heart beats on an average

of 72 times per minute, in children it is higher. The frequency of beat is influenced by age, sex, disease, drugs, physical causes and digestion.

Valves and Openings.

Right Auricle.—Leading off from the right auricle anteriorly and superiorly is a sinus that bears the name of the auricular appendix. It is a little hollow pouch capable of distention with blood.

Opening into the right auricle we find the coronary veins, the two venæ cavæ, and the auriculo-ventricular opening. Guarding these openings are valves to cause the constant onward flow of the blood current.

Right Ventricle.—Opening into the right ventricle are the pulmonary artery and the right auricle.

The tricuspid valve guards the auriculo-ventricular opening. It is composed of three triangular shaped membranes attached to the base of the circumference of the opening and the apices of the triangles coming together when closed.

The semi-lunar valves guard the pulmonary opening. They are three entirely separate segments of semi-lunar shape and are attached by their long curved margins to the circumference of the artery just where it springs from the muscular substance of the ventricles.

Left Auricle.—Like the right auricle, this cavity has a small sinus leading off from it anteriorly and superiorly—the auricular appendix. The openings into this are the four pulmonary veins and the left ventricle.

The tricuspid or mitral valve guards the left auriculo-ventricular opening.

Left Ventricle.—This ventricle has the thickest walls and does the most work of all the cavities of the heart, because it forces the fresh arterial blood out into the aorta to supply the systemic circulation.

The aorta and the right auricle open into this ventricle. The aortic semi-lunar valves guard the aortic opening. They are three distinct semi-lunar shaped membranes to close the aortic opening at the end of systole.

The mitral valve closes the auriculo-ventricular opening. It is just like the tricuspid only it has two flaps instead of three.

Function of valves.—The valves are arranged at the openings of the heart so the blood will be forced in a constant direction and no regurgitation into back cavities allowed. When the auricles are at systole the auriculo-ventricular valves are open thus letting the flow of blood go from auricles to ventricles; but as soon as auricular diastole and ventricular systole begins these valves shut and the blood is kept from regurgitating into the auricles. Then the semi-lunar valves are open and the blood is forced into the aorta and pulmonary artery. When the ventricular diastole begins these semi-lunar valves close and the blood is prevented from running back into the heart from the arteries.

Work of the Heart.—The work done by the heart is equal to the weight of a column of blood multiplied by the height or distance to which this column is carried by the heart force. The column of blood is that amount that is sent by a single contraction of the heart and the height to which it is carried is equal to the pressure in the aorta and pulmonary arteries.

The amount of blood thrown into the aorta at each contraction of the ventricles weighs about 87 grams (about 3 oz.) and the height to which it is forced is about 1.5 meters or 5 feet in man.

In estimating the work of a machine the English express the result in **foot pounds.** The French in **grammetres.** A **foot pound** is the energy expended in raising a unit weight (1 lb.) through a unit distance (1 ft.). A grammetre is the force expended in raising one gram one meter. Thus the work of the left ventricle at each contraction is 130.5 grammetres (or 15 foot pounds). Add 45 grammetres as the work done by the right ventricle in

contracting. If the heart beats 72 times per minute it will in twenty-four hours do 18,000 kilogramme-metres of work.

Sounds of the Heart.—Listening to the heart's action through the thoracic wall we have two distinct sounds. The **first** is a slightly elongated sound and comes immediately after the beat of the radial pulse. It is characterized by the syllable **lub.** The cause of this sound is supposedly the closure of the auriculo-ventricular valves combined with the sound made by the contracting muscle. It can best be heard over the apex of the heart.

The **second** sound is shorter and sharper than the first and is heard just before the impulse of the radial pulse. It is characterized by the shorter syllable **dup.**

The cause of this sound is supposedly the closure of the aortic semi-lunar valves along with those of the pulmonary artery. It is best heard in the right second intercostal space, as the aortic current transmits it.

Certain diseases affect the heart valves and the sounds then depart from the normal. Thus it is of importance to know the cause and sound of the normal vibrations so as to detect the diseased conditions.

Heart Innervation.—The nerves that inhibit the action of the heart are the two **vagi**; cutting these results in increase of pulse frequency. In normal beating the vagi are continually stimulated. How the vagus acts on cardiac muscle is not known.

The nerves that accelerate the action of the heart are the **nervi accelerantes,** which are branches of the sympathetic system. Stimulation of these causes increase in force and frequency of heart beats.

II. CIRCULATION IN BLOOD-VESSELS.

Taking the heart as a central station for supplying force, we find the blood current constantly going from a place of higher pressure to a place of lower pressure.

The highest pressure is in the muscular center, the heart.

Blood-vessels connect with both auricles and ventricles. Those connecting with the ventricles and carrying blood away from the heart are called arteries and the pressure in these is high, but lower than in the heart. Those vessels connecting with the auricles and carrying blood back to the heart are called veins and the pressure is lowest of all in these.

The minute vessels that connect the arteries and veins and collect waste from and supply nutritive material to the lymph stream, are called capillaries. The pressure in these is lower than in the arteries but higher than in the veins.

FIG. 28.

Tracing of blood pressure taken with Fick's manometer. (*Yeo.*)

The blood is thus kept in motion, constantly going from place of higher to lower pressure.

The completed circulation is thus:—

(Beginning with the right auricle of the heart.) The two venæ cavæ pour venous blood into the right auricle and it in turn empties its contents into the right ventricle. From here the blood is driven into the pulmonary artery (carrying venous blood) to be aerated in the lungs. From lungs it comes by pulmonary veins (carrying arterial blood) to the left auricle. This is the lesser or pulmonary circulation.

From left auricle the blood goes into the left ventricle and from here it is forced into the aorta and thus into the systemic arteries, then through the capillaries to the veins and back by means of venæ cavæ into the right auricle.

Thus the cycle is complete and in man it takes supposedly twenty-two seconds.

STRUCTURE.

THE BLOOD-VESSELS.

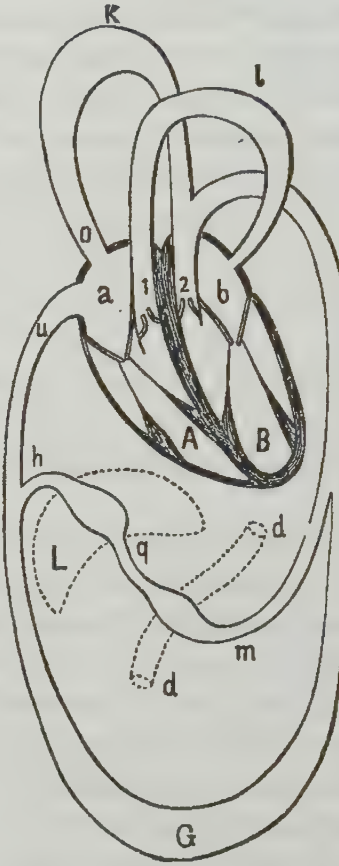
Arteries.—The arteries have three coats: (1) the external coat called the **tunica adventitia,** which is composed of fibrous

tissue with a little plain muscular tissue; (2) middle coat or **tunica media,** composed of yellow, elastic tissue; and (3) the inner coat or **tunica intima,** composed of epithelium on basement membrane.

Veins.—The veins also have three coats, the external, middle and internal, as the arteries; but the middle coat is composed chiefly of inelastic, fibrous tissue. Thus the veins lack the elasticity and contractility given to the arteries by the middle coat.

The Capillaries.—As the arteries get smaller we find them still composed of the three above named coats. Finally, though, in the minutest vessels we find only the innermost layer remaining. These one-coated vessels are the capillaries, and they have only one layer of epithelial cells on a basement membrane. This is in order to render possible the interchange of material between the blood current and the lymph stream, so the tissues may be nourished and the waste products removed.

FIG. 29.



Scheme of the circulation.

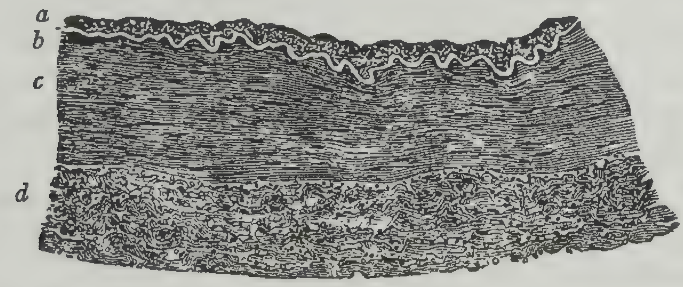
a, right, *b*, left, auricle; *A*, right, *B*, left, ventricle; 1, pulmonary artery; 2, aorta; 1, area of pulmonary, *K*, area of systemic, circulation; *o*, the superior vena cava; *G*, area supplying the inferior vena cava, *u*; *d*, *d*, intestine; *m*, mesenteric artery; *q*, portal vein; *L*, liver; *h*, hepatic vein. (*Landois.*)

IMPORTANCE OF ARTERIAL ELASTICITY.

If an amount of fluid corresponding to that of the "pulse volume" be suddenly injected into the end of a rubber tube already distended with liquid, the tube will be further distended by the

liquid injected; but if a like amount of fluid be allowed to escape at the other end the tube will resume its original caliber. Thus the pulse volume enters with much force the aorta or pulmonary artery; the artery is very elastic and expands under this influence, but immediately recoils with a great pressure on the contents. The pressure tends to force the blood along the vessel in both directions, but its return into the ventricle is effectually prevented by the close of the semi-lunar valves. Consequently it can go only toward the periphery.

FIG. 30.



Transverse section of part of the wall of the posterior tibial artery. (Man.) (From *Yeo* after *Shafer.*)

a, endothelium lining the vessel, appearing thicker than natural from the contraction of the outer coats; *b*, the elastic layer of the intima; *c*, middle coat composed of muscle fibers and elastic tissue; *d*, outer coat consisting chiefly of white fibrous tissue.

Now it is evident that the flow in the beginning of the aorta is intermittent; but it is found that, in vessels as large as the carotids and smaller the flow has resumed a remittent character. The smaller the vessel becomes the nearer is the flow continuous until this condition is established in the capillaries.

It is the elastic coat of the arteries that allows them to expand and then contract on the contents forcing them onward. Furthermore it is this elasticity that in the main causes the intermittent and remittent flow to become continuous. So the function of the elastic coat is two-fold; first, it forces the blood current continuously toward the periphery, and second, it is chiefly the

cause of the change from an intermittent flow to a constant flow, which is of so much importance in the capillaries.

Rate of Flow.—The rate of flow of the blood or its **velocity** is equal to the volume flowing through a determined section in one second divided by the cross section. The rate is determined by the pressure, the friction in the vessels, and the cross section of the vessels.

The combined cross section of the capillaries is greater than the combined cross section of the arteries or the veins, so the rate of flow must be greater in the arteries and veins than in the capillaries. The friction is greater in the smaller vessels than in the larger which retards the flow. The pressure is greater in the arteries than in the capillaries and veins. From these facts it is evident that the velocity is greater in the arteries than in the capillaries and veins, but increases in the veins as compared to the capillaries.

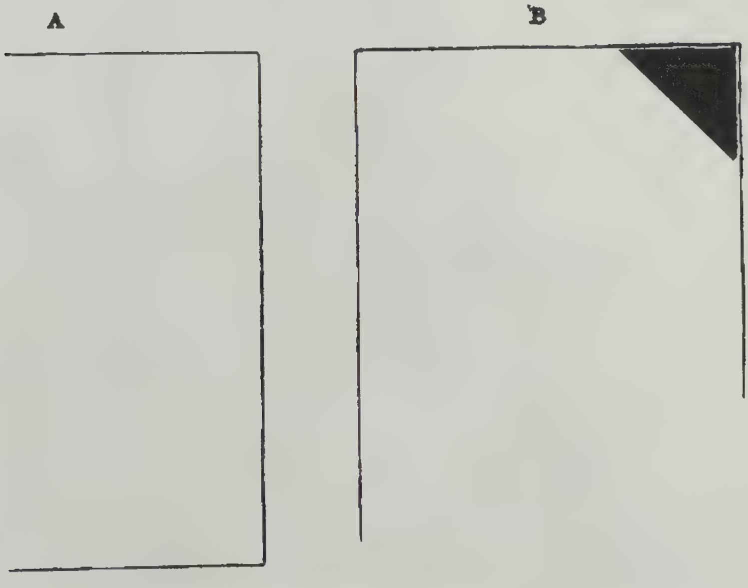
In the large arteries the rate is 200–400 mm. per second, in the capillaries. 6–8 mm. and in the large veins it is but little less than in the arteries.

Valves in the Veins.—At frequent intervals in the course of the veins are found small folds of membrane protruding into the lumen of the vessels. The flow of the blood in the veins is more sluggish than in the arteries, because, as we have seen, the pressure lessens in the veins while gravity and friction tend to cause a stoppage. These protruding folds of the mucous membrane or **valves** found in the veins aid in the circulation by overcoming gravity and preventing a backward flow of blood, by holding the blood until a fresh impulse can impel it forward. They are found in pairs and are most abundant in the veins of the extremities where gravity tends to impede the onward flow of the current.

Capillary Importance.—The capillaries are the smallest blood-vessels and the most important as to function. Being of only one thickness of epithelium and in direct touch with the lymph flow, we can readily see that the food products brought by

the arterial blood can be exchanged here for waste brought by the lymph. The flow in the capillaries is constant, as we have seen, and we can see the importance of this when we take into consideration how rapidly the tissues use oxygen and how necessary is a constant increasing supply, and how essential it is to remove the carbon dioxide poisons.

FIG. 31.

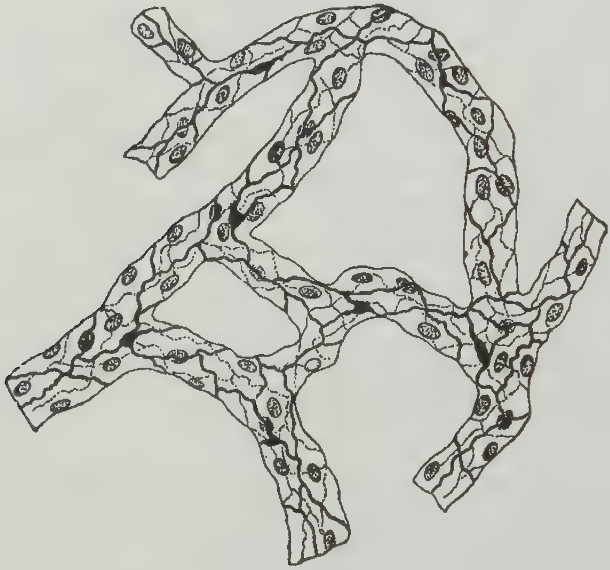


A, vein with valves open. B, with valves closed; stream of blood passing off by lateral channel. (*Kirkes* after *Dalton*.)

Innervation of Vessels.—The blood-vessels are controlled by the sympathetic nervous system by means of the **vaso-motor** nerves. These compose both the **vaso-constrictors,** or the nerves causing the vessels to contract, and the **vaso-dilators,** those causing the vessels to dilate. The entire physiological distribution of blood is regulated by the vaso-motor system of nerves. It is by their means that the blood is increased to all parts of the body where physiological activity is going on, as when the gastro-

intestinal tract is active during digestion, a muscle in motion, or glands in activity. Paralysis of the vaso-constrictors causes blushing, paralysis of the dilators causes pallor as from fright. Outside influences will cause the constrictors to act, as cold; while alcohol will cause dilators to act and paralyzes the constrictors.

FIG. 32.



Capillaries.

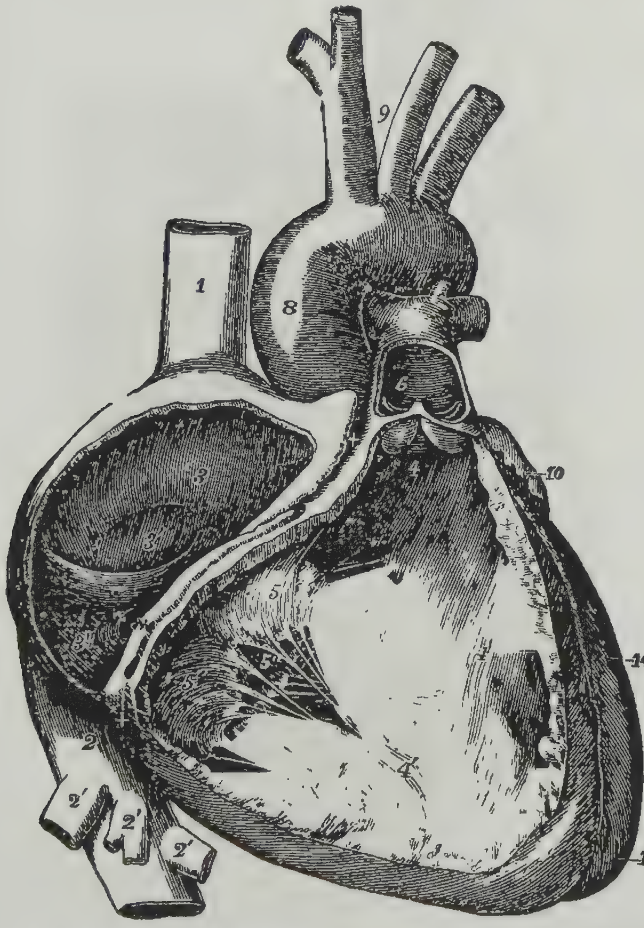
The outlines of the nucleated endothelial cells with the cement blackened by the action of silver nitrate. (*Landois.*)

The chief vaso-motor center is in the medulla oblongata, while subordinate centers exist in the cord. The vaso-motor fibers reaching the vessels proceed from ganglia in the sympathetic system, but these ganglia are influenced by the cells in the vaso-motor center.

Amount of Blood Important.—When there are small losses of blood from slight injuries the entire vascular system contracts and the current supplying this diminished area is sufficient; but at times the loss of blood is so great that the amount remain-

ing is not sufficient to carry on a complete circulation. Unless remedied this results in death. In such cases of great loss the

FIG. 33.



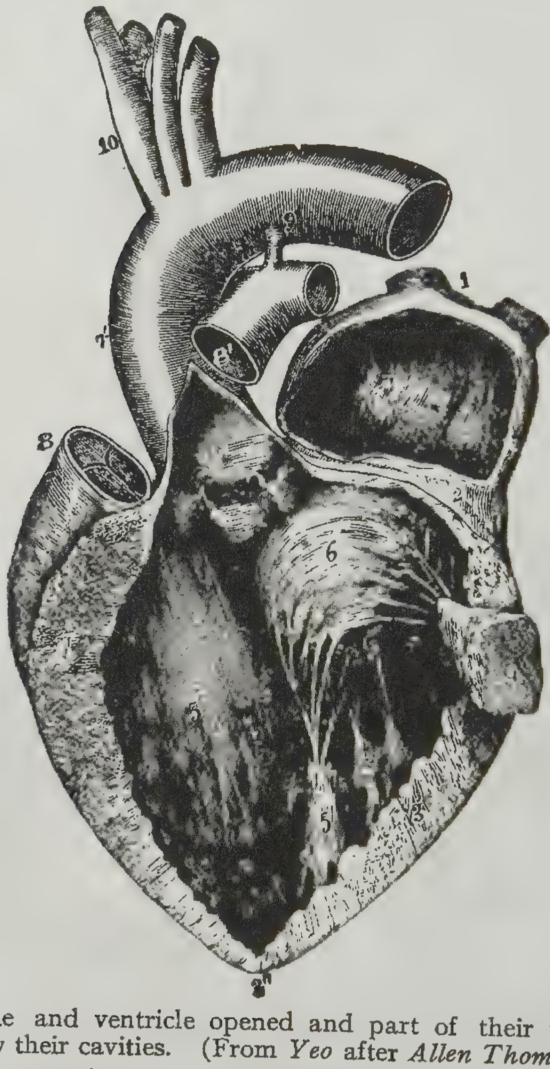
Interior of right auricle and ventricle exposed by the removal of a part of their walls. (From *Yeo* after *Allen Thompson.*)

1, superior vena cava; 2, inferior vena cava; 2', hepatic veins; 3, 3', 3'', inner wall of right auricle; 4, 4, cavity of right ventricle; 4', papillary muscle; 5, 5', 5'', flaps of tricuspid valve; 6, pulmonary artery in the wall of which a window has been cut; 7, on aorta near the ductus arteriosus; 8, 9, aorta and its branches; 10, 11, left auricle and ventricle.

deficit may be supplied by a normal salt solution, thus giving an amount of fluid sufficient to maintain the heart action. But in cases where as much as two-thirds of the blood is lost, the injec-

tion of fluid does no good. The amount to cause the heart's action to continue may be supplied, but the amount of hemoglo-

Fig. 34.



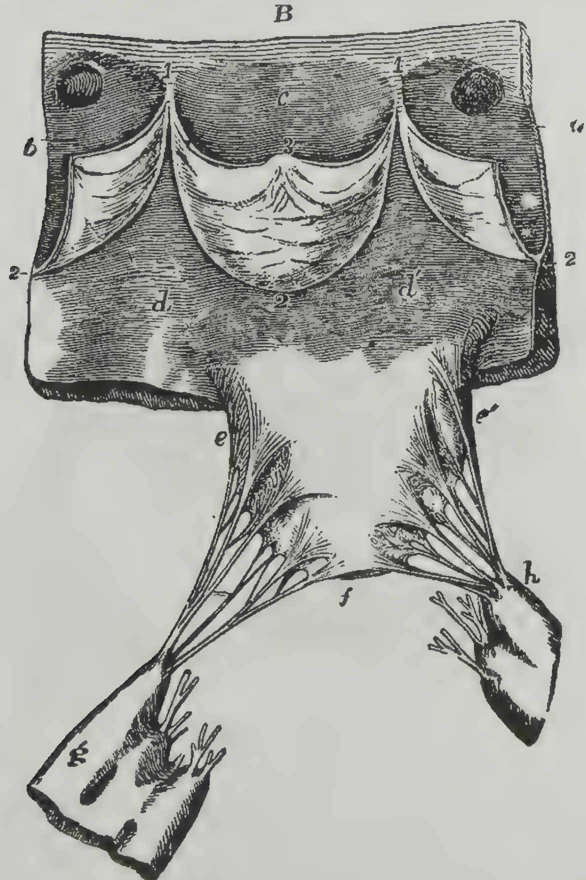
The left auricle and ventricle opened and part of their walls removed to show their cavities. (From *Yeo* after *Allen Thompson*.)

1, right pulmonary vein cut short; 1', cavity of left auricle; 3, 3'', thick wall of left ventricle; 4, portion of the same with papillary muscle attached; 5, the other papillary muscles; 6, 6', the segments of the mitral valve, 7, in aorta is placed over the semi-lunar valves. (*Yeo.*)

bin necessary for life is lost and this cannot be supplied. Asphyxiation is the result.

Pulse.—Placing a finger on any artery in the body and there will be transmitted to it a perceptible impulse. This impulse is what is called the pulse, and it is the force of the heart's action

FIG. 35.



Portion of the wall of ventricle.

d, *d'*, and aorta, *a*, *b*, *c*, showing attachments of one flap of mitral and the aortic valves; *h* and *g*, papillary muscles; *e*, *e'* and *f*, attachment of the tendinous cords. (From *Yeo* after *Allen Thompson*.)

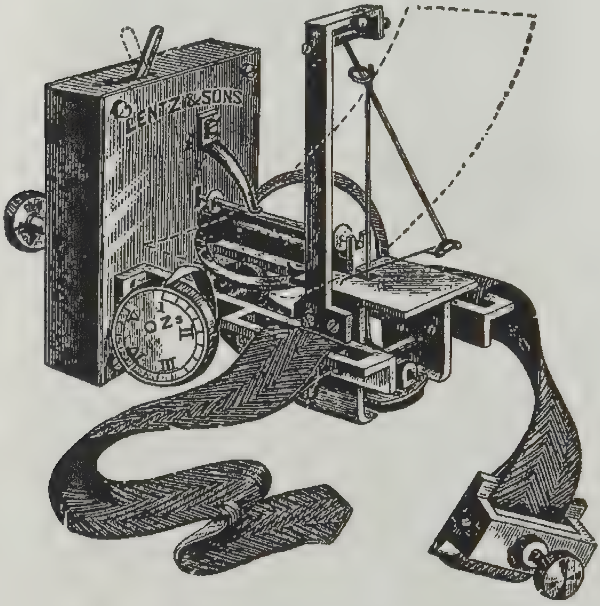
against the elastic arterial wall, and the subsequent contraction of this wall against the current it contains.

The impulse is an index to the condition of the circulation. Its frequency normally in an adult is about 72 times per minute,

in children it is higher, and it is more frequent in woman than in man. Its frequency is affected by age; sex; exercise; disease; drugs; and psychical causes, as fear, joy, sorrow, etc. We feel the pulse to learn several things:—(1) its frequency, which tells how many times the heart is beating.

(2) Its tension, which is the state of the arterial walls and is

FIG. 36.



Dudgeon sphygmograph.

the resistance offered in peripheral vessels. We judge the tension by the force necessary to obliterate the impulse.

(3) Regularity, which tells whether the heart is regular in either its force or rhythm.

(4) Its strength, which tells as to the force with which the heart is acting.

(5) Its length, whether the beat is long or slow and continuous.

(6) The condition of the vessel wall, whether sclerotic or not.

In the study of the pulse an instrument called the sphygmograph

is used, which receives the impulse from a beating artery and transmits it by means of a finely adjusted lever to a smoked surface of paper. Thus a graphic representation of the impulse is given, the height to which the writing end of the lever goes denoting the force of the impulse of the heart beat at the time of the writing.

THE LYMPH.

The lymph is a clear colorless fluid contained in the lymphatic vessels and tissue spaces. It resembles plasma in general appearance and does not differ greatly from it in composition.

The Lymph Vessels.—These vessels originate in at least three different ways. (1) All cells may be said to be bathed in lymph, being surrounded by that fluid lying in the irregularly shaped spaces between them. These spaces communicate with each other and finally converge to the lymph capillaries. The intervals are called the "*extravascular lymph spaces.*" (2) In certain situations, particularly in the nervous centers, the small blood-vessels are completely surrounded by and included in larger tubes, the "*perivascular lymph canals.*" These likewise pass on to the lymph capillaries proper. (3) The large *serous cavities*, like those lined by the peritoneum, pleura, tunica vaginalis, etc., have large numbers of lymphatic radicles opening abruptly into them, or rather originating from them, and these may be considered as great extravascular lymph spaces.

The **course** of the lymph is from the tissues to the subclavian veins, where it enters the vascular circulation. The lymphatic vessels from the right arm and the right side of the face, head and chest converge to form the *ductus lymphaticus dexter*, which enters the right subclavian vein at its junction with the internal jugular. The lymphatics from all other parts of the body converge to form the *thoracic duct*, which enters the left subclavian vein at its junction with the internal jugular. The thoracic duct begins by a dilated pouch lying upon the second lumbar

FIG. 37.

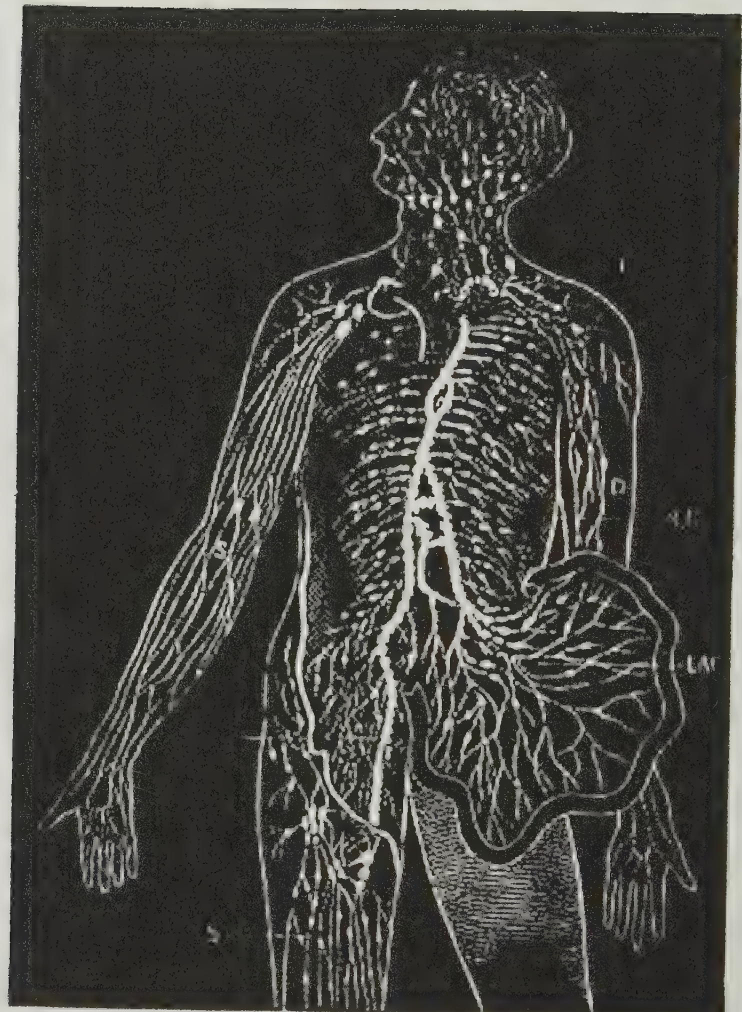


Diagram showing the course of the main trunks of the absorbent system.

The lymphatics of lower extremities, D, meet the lacteals of intestines, LAC, at the receptaculum chyli, R.C., where the thoracic duct begins. The superficial vessels are shown in the diagram on the right arm and leg, S, and the deeper ones on the left arm, D. The glands are here and there shown in groups. The small right duct opens into the veins on the right side. The thoracic duct opens into the union of the great veins of the left side of the neck, T. (*Yeo.*)

vertebra. This pouch receives the 1–4 lymphatic branches which have converged from the lacteals, and is called the *receptaculum chyli.* The lacteals pass through the mesenteric lymphatic glands on their way to the receptaculum chyli.

The distribution of the lymphatics needs no comment when it is known that they receive the plasma which has been passed out of the vascular capillaries and thus collect fluid from well-nigh every tissue in the body.

The **structure** of the lymphatics is quite similar to that of the veins, though they are more delicate. The lymph capillaries probably contain only a single coat like the venous capillaries. In the large vessels this thin endothelial coat is supplemented by connective tissue fibers together with some elastic and non-striated muscle fibers. They are very abundantly supplied with valves which operate in the same way as the venous valves. The vessel wall is quite elastic and has some contractile power.

Lymphatic Glands.—All the lymphatics pass through one or more lymphatic glands on their way to the larger trunks. These bodies are not true glands. Their structure is adenoid. There are some six or seven hundred in the body, varying in size from a pinhead to a large bean. The superficial glands are especially abundant about the groin, axilla, neck and the other flexures. The deep ones are most numerous about the great vessels. The mesenteric glands are found between the folds of the mesentery.

The lymphatic glands are of irregular shape and contain within their substance large numbers of lymph spaces or canals through which the incoming lymph must pass. The *vasa efferentia* are usually fewer in number and larger in size than the *vasa afferentia.* The current must be considerably delayed in the glands. They are probably concerned in the elaboration of leucocytes of the lymphatic circulation, while their retention of toxic materials—even to their own hurt—is a common pathological occurrence.

Properties and Composition of Lymph.—Lymph is a com-

paratively clear liquid containing leucocytes. After meals the color becomes whitish from the admixture of chyle, and numerous fat droplets are present. Neither red corpuscles nor platelets are thought to be found in lymph except accidentally. The specific gravity is lower than that of the blood. Lymph coagulates when drawn, since the fibrin factors are present; but the process is less prompt and the clot is less firm than in case of blood.

In order to form an idea as to the constituents of lymph it is only necessary to say that its ultimate origin is the blood plasma, except in so far as its composition is changed during digestion. The plasma makes its way through the capillary walls out to the tissues bringing nourishment to them and removing waste products from them. In thus coming in contact with the tissues the plasma finds itself in the extravascular lymph spaces and its name is simply changed to lymph. It thus appears that lymph may enter the extravascular spaces by the direct passage of plasma out of the vessels or by being excreted, as it were, from the tissue cells.

In any case the constituents of lymph are not very different from those of plasma, except, of course, when intestinal digestion is in progress and chyle is introduced into the lymphatic circulation. It contains the three *plasma proteids*, *urea*, *fat*, *lecithin*, *cholesterin*, *sugar* and *inorganic salts*. The proteids are less abundant than in plasma, as might be supposed when it is remembered that they possess little osmotic power. The inorganic salts are in about the same proportion in both fluids. It is significant that the amount of urea and related excrementitious products is more abundant in lymph than in plasma; their source is the destructive metabolism going on in the cells to which the plasma has been supplied, this plasma finding its way back as lymph. It is by no means certain, however, that all the plasma escaping from the capillaries is carried away by the lymphatic system. Some may reënter the blood-vessels.

There is no unanimity of opinion as to the exact method of passage of plasma through the capillary walls into the lymph spaces. Some maintain that the phenomena can be explained by the ordinary physical laws of diffusion, filtration and osmosis when existing conditions of pressure, etc., are taken into consideration. Others hold that these laws are insufficient in themselves to account for various occurrences in this connection, and ascribe to the capillary endothelium some active secretory power governing, or at least influencing, the outward passage of the plasma.

The Flow of Lymph.—There is no organ corresponding to the heart to keep the lymph current in motion. The main causes for its direction from the extravascular spaces toward the veins in the neck is the degree of *pressure* to which it is subjected in those spaces as compared with the inferior, or even "negative," pressure obtaining near the terminations of the great ducts. It is known that at all times the venous pressure in the subclavian veins is low and that it may even fall below the atmospheric pressure, so that "suction" is exerted upon the lymphatic ducts where they enter those vessels. The lymph pressure in the extravascular spaces is estimated to be one-half the capillary blood-pressure. Friction and gravity (where the course of the vessels is upward) oppose the passage of the fluid. Consequently it accumulates in the spaces and in the smaller lymphatics until the pressure there becomes greater than the resistance of these forces, when it passes onward. Since lymph is being continually produced this superior pressure in the extravascular spaces and small lymphatics is a fairly constant factor and keeps up a correspondingly constant current.

There are two factors which are accessory to this peripheral pressure: (1) *Thoracic aspiration* by bringing about negative pressure in the veins in and near the chest brings about a like condition in the tributary lymphatic ducts; furthermore, the effect of aspiration makes itself felt directly upon the thoracic

duct since its greatest extent is in the thorax. (2) The *valves* of the lymphatics act in a similar manner to those of the veins and constitute a very necessary factor in the lymphatic circulation. Although the lymph flow resembles that of the venous blood, it is less regular and more sluggish, but probably not so slow as might be supposed. Properly colored solutions injected into the blood have been demonstrated in the lymph of the thoracic duct "in from four to seven minutes."

Lymph and Chyle.—It is scarcely necessary to refer to the differences between these two fluids. Chyle is the intestinal lymph during digestion. In the intervals of digestion the contents of the lacteals do not differ materially from lymph in other localities. Chyle has a whitish milky appearance due to the presence of emulsified and saponified fats. Its specific gravity naturally depends largely upon the amount of fat ingested. but is always higher than that of ordinary lymph and lower than that of blood. Not only is there more fat in the chyle than in lymph, but the other solids are also increased. The proteid constituents are considerably more abundant. For the most part the higher specific gravity is explained by the absorption of solids in solution from the alimentary canal.

Chyle is forced out of the lacteal by contraction of the non-striated muscle fibers which run along by the vessel. When relaxation of the fibers occurs, return of chyle into the lacteal is prevented by a valve at the base of the villus.

CHAPTER VI.

RESPIRATION.

Object.—The object of respiration is to furnish oxygen to the tissues and remove carbon dioxide from them. The intervention of the lungs and blood is necessary to accomplish this end. At each inspiration a certain volume of air is taken into the lungs, and from it, while in these organs, is removed a certain amount of oxygen which enters the blood of the pulmonary capillaries. At each expiration there is removed from the lungs a certain volume of air, and it contains a proportion of carbon dioxide over and above that contained in the ordinary atmosphere, *i. e.*, in the inspired air; this carbon dioxide is removed from the blood of the pulmonary capillaries and enters the air in the lungs. The entrance and exit of air to and from the lungs, in obedience to movements to be noticed later, constitutes what is commonly called **respiration**; but the mere tide of the air inward and outward is of no significance unless the interchange of oxygen and carbon dioxide takes place.

Internal Respiration.—Nor is this interchange of value unless another occurs in the tissues. The oxygen which has entered the pulmonary blood is conveyed by the circulation to a point where the fluid is brought into very close relationship with the tissues (namely, in the capillaries), and is here given up to the cells; furthermore, at the same place the cells give up carbon dioxide to the capillary blood. It is only for the purpose of effecting this last interchange that there is any respiration, or any respiratory apparatus. Inspiration and expiration, the pulmonary interchange of gases, the transportation of oxygen and carbon dioxide

to and away from the cells, are all equally immaterial except as being means to the accomplishment of this end. It would make no difference whether pulmonary respiration were kept up or not if oxygen could be introduced into the blood and carbon dioxide removed from it in some other equally efficient way. So far as the cell is dependent on the acquisition of oxygen and the removal of carbon dioxide, it would make no difference if there were no respiration and no circulation if these materials could be acquired and removed in some other equally efficient way.

On the other hand, it were useless to keep up artificial respiration or to inject oxygen into the lungs if the cells, through some disability, cannot take up the oxygen furnished, or if the circulation cannot absorb or convey the oxygen.

It is seen that, from the standpoint of the blood, the interchange of gases in the lungs is exactly opposite to that in the tissues; that is to say, in the lungs it loses carbon dioxide and gains oxygen, while in the tissues it loses oxygen and gains carbon dioxide. The pulmonary interchange is properly termed **external respiration** in contradistinction to that in the tissues which is termed **internal respiration.**

It is needless to comment upon the universal necessity of oxygen to the life of cells. Its appropriation is to be looked upon as a part of the nutritive process; and, indeed, while in the long run, cells are certainly dependent upon the nutriment furnished by the ordinary aliments, they will retain their vital activity for a longer time when deprived of any or all of these than when deprived of oxygen alone. This gas is more immediately necessary to the maintenance of life than is any other substance.

Since, in order to bring about internal respiration in the human being, the lungs and circulation happen to be necessary, attention will have to be directed to the respiratory phenomena taking place in both.

Anatomy of the Respiratory Organs.

It will be considered that the air has passed through the posterior nares into the pharynx and is ready to enter the larynx.

The Larynx.—This lies in front of the esophagus, its upper opening communicating with the middle pharynx. It is composed of four cartilages and the muscles and ligaments which hold them together. The cartilages keep its lumen constantly open, while the muscles effect movements concerned in degluti-

Fig. 38.

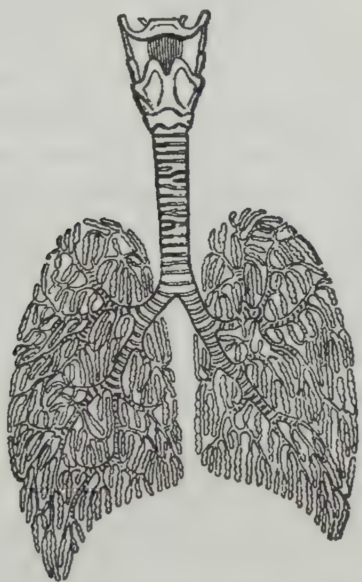


Diagram of the respiratory organs.

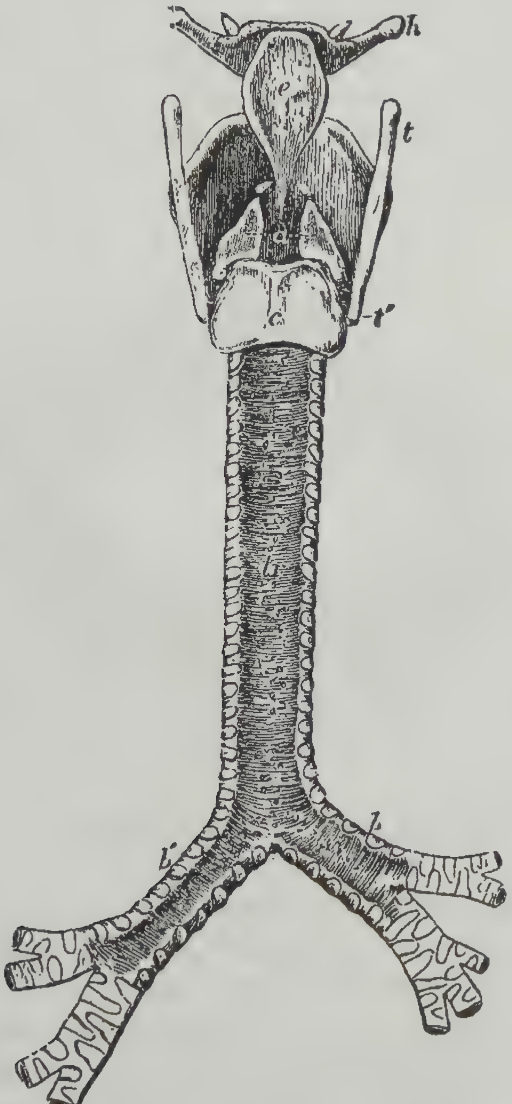
The windpipe leading down from the larynx is seen to branch into two large bronchi, which subdivide after they enter their respective lungs. (*Yeo.*)

tion, respiration and phonation. The cartilages are the *thyroid*, *cricoid* and two *arytenoids*. The two alæ of the thyroid meet at an acute angle in front to form the Adam's apple. The cricoid is at the lower end of the larynx, completely surrounding it. The arytenoids are movable and rest upon the back of the cricoid. (Fig. 39.)

The **vocal cords,** two ligamentous bands covered by a thin layer of mucous membrane, stretch antero-posteriorly across the upper end of the larynx, while the false vocal cords, having nothing to do with phonation, and pinker in color, are above and parallel with the true cords. A small triangular leaflet of fibro-cartilage is attached by its base to the base of the tongue and to the upper anterior part of the larynx. This is the **epiglott's.** It fits accurately over the opening of the larynx, and during the act of deglutition is closed to prevent the entrance of food, saliva, etc. Except during deglutition the epiglottis is raised and there is free passage of air into and out of the laryngeal cavity. The vocal cords are fixed anteriorly to a point between the alæ of the thyroid and posteriorly to the movable arytenoids. Intrinsic muscles have the power of so moving the arytenoids as to separate and approximate the posterior attachments of the cords and thus increase or decrease the size of the rima glottidis. During inspiration these muscles act to separate the cords and allow free entrance of air into the trachea. When this act has ceased they relax and the cords are passively approximated. The expiratory act separates the cords and they afford no obstruction to the exit of air. The inspiratory act, on the other hand, tends to draw the cords together and the active intervention of the muscles is necessary to keep the glottis open.

The Trachea.—The trachea succeeds the larynx in the respiratory tract. It begins at the cricoid cartilage and extends downward for about four and a half inches where it bifurcates to form the right and left *bronchi*, one of which goes to each lung. The trachea consists of an external *fibrous membrane*, between the layers of which are a number of *cartilaginous rings*, and an internal *mucous membrane*. The rings are the most striking part of the trachea. They serve to keep the canal open at all times. The inspiratory effort would otherwise collapse the walls and prevent the entrance of air. These rings are sixteen to twenty in number, and are lacking in the posterior third or fourth of the

FIG. 39.



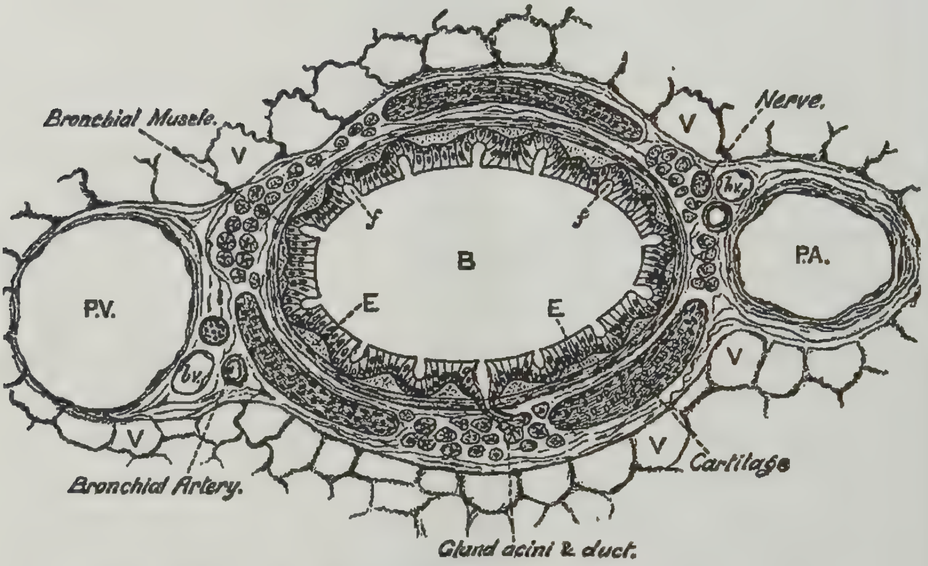
Outline showing the general form of the larynx, trachea, and bronchi, as seen from behind.

h, great cornu of the hyoid bone; *t*, superior, and *t'*, the inferior cornu of the thyroid cartilage; *e*, epiglottis; *a*, points to the back of both the arytenoid cartilages, which are surmounted by the cornicula; *c*, the middle ridge on the back of the cricoid cartilage; *tr*, the posterior membranous part of the trachea; *b*, *b'*, right and left bronchi. (*Kirkes* after *Allen Thomson*.)

circumference. They are, therefore, not true rings. The interval between their ends is filled with fibrous and non-striped muscular tissue. The mucous membrane is lined by ciliated epithelium, and has mucous glands in its substance (Figs. 38, 39.)

The Bronchi.—The primitive bronchi are of the same essential structure as the trachea. The right is the larger, shorter,

FIG. 40.



T.S, intra-pulmonary bronchus of cat. PA and PV, pulmonary artery and vein; bv, bronchial vein; V, air vesicles. (*Stirling.*)

and more nearly horizontal. This probably accounts for the more frequent lesions in the right lung. Penetrating the lung substance they divide and subdivide until each, by its ramifications, communicates with every air vesicle in that lung. When the primitive bronchus has divided, the incomplete cartilaginous rings are replaced by irregular plates of cartilage, which are so arranged as to completely encircle the tube. These extend as far as the division of the tubes into branches $\frac{1}{50}$ in. in diameter.

Surrounding the tubes in the lung substance is a circular layer

of plain muscular fibers; these cease only at the air vesicles. Elastic fibrous tissue is also present everywhere in the bronchial walls and is continued over the vesicles themselves.

Bronchial tubes *above* $\frac{1}{50}$ in. in diameter have in their walls *cartilaginous plates, muscular tissue, fibrous elastic* and *inelastic tissue* and a lining membrane of *ciliated epithelium.*

Bronchial tubes $\frac{1}{50}$ in. in diameter, and smaller, have in their walls the same elements *excepting the cartilage;* but as the tubes subdivide their walls grow continuously thinner, and the inelastic tissue becomes less and less in amount, until it finally practically disappears; the ciliated epithelial cells gradually give place to a single layer of squamous cells in the smallest tubes. The smallest bronchial tubes, the **bronchioles,** are from $\frac{1}{120}$ to $\frac{1}{70}$ in. in diameter. Of course everywhere in the walls there are vessels and nerves.

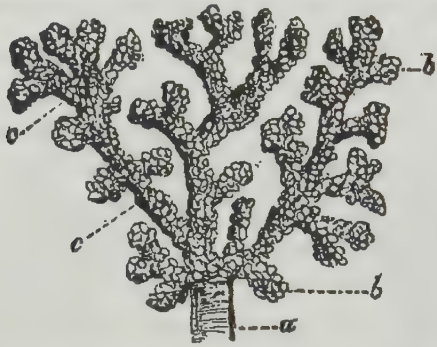
The Air Vesicles.—Each bronchiole opens into a collection of air vesicles, or cells, called a pulmonary lobule. The term **lobulette** will be here applied to it, however, reserving the word *lobule* for a collection of lobulettes about $\frac{1}{4}$ in. in diameter. The bronchiole entering the lobulette becomes the *infundibulum* (Fig. 41), a slightly dilated canal from which are given off from eight to sixteen oblong *vesicles*, the true *air cells.* The cells are a little deeper than they are wide and end in blind extremities. The diameter of the lobulette is about $\frac{1}{50}$–$\frac{1}{12}$ in.; that of the vesicle about $\frac{1}{200}$–$\frac{1}{70}$ in. It has been estimated that there are some 725,000,000 of these vesicles in the lungs and that their combined area is something over two hundred square yards.

The walls of the air cells are very thin, being composed of a single layer of *flattened epithelium* together with *highly elastic fibrous tissue.* Ramifying in this latter is a most abundant supply of capillaries, which are larger here than anywhere else in the body. The physical conditions are most favorable for the exchange of gases between the blood and air, each capillary being exposed to vesicles on both sides, and the air and blood being

separated only by the very thin walls of the capillary and vesicle. The elastic tissue is very important in expelling the air from the cells when the inspiratory effort has ceased.

For the nutrition of the bronchi and lung substance arterial blood is furnished by the **bronchial artery,** which enters and

FIG. 41.



Terminal branch of a bronchial tube, with its infundibula and air-sacs, from the margin of the lung of a monkey, injected with quicksilver.

a, terminal bronchial twig; *b b*, air-sacs; *c c*, infundibula. × 10. (*Kirkes* after *E. E. Schulze.*)

ramifies with the bronchi. The entire mass of venous blood passes directly from the heart through the **pulmonary artery** to the lungs to be arterialized, and it is the capillaries of this artery which furnish the abundant network between the air cells.

The **lungs** have the shape of irregular cones, their bases resting on the diaphragm and their apices extending to points a little above the clavicles. They are completely separated from each other by the mediastinum and their external surfaces are covered by the pleura, a serous membrane similar to the peritoneum and reflected from the thoracic wall. The right lung is divided by fissures into *three lobes* and the left into *two*. Superficially the lung substance is seen to be subdivided into areas about ¼ in. in diameter called the *lobules*. Each lobule is composed of a number of lobulettes as above mentioned.

Mechanism of Respiration.

Respiration implies the more or less regular entrance and exit of air to and from the lungs. The entrance is **inspiration;** the exit **expiration.** Now, *the thorax is a closed cavity*, notwithstanding the fact that the lungs have an opening (the trachea) by which they communicate with the external air; and, so far as the simple ingress and egress of air is concerned, the question of pulmonary respiration resolves itself into one of pure mechanics. The lungs may be looked upon as a bag (or two bags) in the thoracic cavity. Inspired air does not enter the thoracic cavity, but this bag which is in it. This fact is of the greatest importance.

Furthermore, the lungs are everywhere *in contact with the thoracic wall* by their pleural surfaces. They are composed very largely of highly developed elastic tissue, but are perfectly passive themselves. That is to say, they possess no power of expansion except in obedience to extraneous influences. As found in the thorax they possess a contractile power, but only because certain forces have put their elastic tissue on the stretch, and the contraction is a simple effort of the tissue to return to the condition which characterized it before it was subjected to the expanding force.

Before birth there is no air in the lungs, and this is the only time when the elastic tissue is not on the stretch. The bronchioles and air cells are collapsed, but the thorax is contracted and the pulmonary and thoracic walls are in contact by their respective pleural surfaces. When the child is born an inspiration fills the lungs and they are never thereafter devoid of air. They collapse to a certain extent and leave the thoracic wall when the chest is opened, but cannot empty themselves entirely because the walls of the bronchioles collapse before all the air can escape. This collapse of the lungs when the chest wall is opened shows that the lung structure is in a constant state of *tension*, which

tension has always a tendency to empty the lungs, but cannot do so because the *thorax* can contract only so far, and when its contraction has reached its limit, for the lung to contract farther would mean a separation of the pulmonary and thoracic walls and the formation of a vacuum between them. The additional reason above given, namely the collapse of the bronchioles before all the air can escape, is inoperative under normal conditions and need not be considered.

Causes of Respiratory Movements.—Seeing that the lung structure has always a tendency to empty itself of air, it follows that inspiration cannot be dependent upon the lung itself. Granting, from the physical conditions present, that the lungs and thorax must expand and contract together, the expansion of the lungs in inspiration is *a consequence and not a cause* of the thoracic expansion, and the contraction of the lungs in expiration is *a cause and not a consequence* of thoracic contraction. This statement as to expiration applies only to ordinary tranquil respiration, as will be seen later. Speaking broadly then, inspiration is an *active* and expiration a *passive* process. That is, inspiration occurs as a result of the activity of certain muscles which operate to expand the thorax, and expiration as a consequence simply of the cessation of activity on the part of those muscles and the passive contraction of the lung tissue.

The relation of the thorax and lungs and the action of each in respiration may be illustrated. Suppose a bellows, which, say for some mechanical reason, cannot completely collapse and which is itself air-tight, to contain a thin rubber bag communicating by a tube with the external air; suppose the bag conforms in general outline to the shape of the bellows, and under a moderate degree of distention completely fills the cavity of the bellows when the latter is collapsed as far as possible. Now, it being understood that the bag was somewhat distended to cause it to fill the bellows, and that all air has been allowed to escape by a temporary opening from between the walls of the two and

the bellows itself made air-tight afterwards, it follows that unless the bellows can contract the bag will remain distended and will not leave the bellows wall, although it will have a constant *tendency* to do so. It is also apparent that, since the bag exerts a continual compressing effect on its contents, the pressure inside it will be greater than that outside between it and the bellows wall. Under these conditions there will be a constant tendency on the part of the bellows to collapse, and some *active* force will be necessary to expand it; when it is made to expand the contained bag will expand with it. Suppose the expansion to be stopped at a certain point and the bellows held (to prevent contraction); it is obvious that now the pressure inside the bag is greater, while that outside between its walls and those of the bellows is less, than when the expansion began; that is, the bag has become distended more and is exerting a greater compressing effect upon its contents. If now the bellows be simply *released*, both the bag and the bellows will contract and the former will empty itself so far as the latter will allow; but when the bellows has reached the limit of its contraction the bag also ceases to contract, although it remains in a constant state of tension. If at any time air be admitted to the bellows proper the bag will at once collapse.

This illustration can be applied to the mechanical principles obtaining in ordinary respiration. The bellows is the air-tight thorax which cannot contract beyond a certain point; the rubber bag is the elastic lungs under constant tension, communicating by the trachea with the external air and following, or being followed by, the movements of the thorax; the pressure in the bag and between it and the bellows wall represents the intrapulmonary and intrathoracic pressures respectively.

It will be noticed later that this illustration does not go quite far enough to explain a few of the phenomena of expiration, but it could very easily be made to do so.

Inspiration.—Any force which *expands the thorax* aids in in-

spiration; and any muscles which increase any of the thoracic diameters expand the thorax. The diameters increased are chiefly the (1) *vertical* and (2) *antero-posterior.*

The **vertical** is increased by *descent of the diaphragm*, which descent is caused by its contraction, since, owing to the intra-thoracic "pull" exerted upon it, it is normally vaulted upward.

The **antero-posterior** diameter is increased chiefly by the *elevation of the ribs.* Since these bones, attached posteriorly to the spinal column, run not only forward but also downward to join the sternum by the costal cartilages, it follows that the elevation of their anterior ends will increase the diameter in question.

Muscles of Inspiration.—Elevation of the ribs is effected by a number of muscles. The three *scaleni* are attached above to the cervical vertebræ and below to the first and second ribs; their action elevates not only these ribs but the whole anterior chest wall.

The action of the *intercostales externi* is still a subject of dispute in connection with the physiology of respiration. These muscles are attached externally to the adjacent borders of the ribs, and thus occupy the intercostal spaces. Their fibers are directed downward and forward, and the effect of contraction of any single intercostal muscle would be to approximate the two ribs to which it is attached; but if it can be assumed that the first rib is fixed, then, from the direction of their fibers, the external intercostals will render the ribs more nearly horizontal by raising their anterior movable extremities. It seems that the first rib is prevented from descending, probably by the simultaneous contraction of the scaleni. The *intercostales interni* have a direction almost at right angles to that of the externi; the sternal portions of these act from the sternum and also elevate the anterior extremities of the ribs. The *levatores costarum* are attached to the transverse processes of the dorsal vertebræ and to the upper borders of the ribs posteriorly. The transverse processes are fixed points and the ribs are movable on their spinal

articulations. Contraction of these muscles is, therefore, very efficient in elevating the anterior ends of the ribs.

The action of the *diaphragm* is the most notable of the muscular phenomena connected with respiration, and it deserves to be called the "*muscle of respiration.*"

These are the muscles which are chiefly concerned in *ordinary inspiration*. Their combined action also increases slightly the transverse diameter of the chest. But there are certain others, known as *auxiliary muscles of inspiration*, which are called into play during profound or forced inspiration. Their action is evident from their attachments—all operating chiefly to increase the antero-posterior diameter. They are the *serratus posticus superior, sterno-mastoideus, levator anguli scapulæ, trapezius, pectoralis minor, pectoralis major* (*costal portion*), *serratus magnus, rhomboidei* and *electores spinæ*. It will be noticed that several of these which usually take their point on the chest, as, for example, the sterno-mastoideus, pectorales, etc., must, in order to aid inspiration, take their fixed points at their other extremities.

Expiration.—When the force which expands the chest during inspiration ceases to operate, expiration follows. Not only does the elastic (1) *lung tissue* force out the air, but the (2) *thoracic walls*, by their costal cartilages and their intercostal tissues, are themselves elastic, and this elasticity, aided by the (3) "*tone*" of the muscles which have been put upon the stretch during inspiration and which are now seeking to return to their normal condition, tends to restore the thorax to the dimensions it had previous to the inspiratory act. So far no actual muscular contraction has been brought into play, and it is here assumed that none is usually concerned in the expiratory act of ordinary tranquil respiration.

Some maintain that the costal portions of the *intercostales interni* particularly are expiratory in quiet breathing; they do contract and the ribs approach each other during the act, but it

is probable that they serve only to maintain the proper degree of tension of the intercostal tissues.

Although the elastic reaction of the lung tissue during expiration operates together with the elasticity of the thoracic wall in diminishing the antero-posterior diameter of the chest, it is chiefly effective in diminishing the vertical diameter by *raising the diaphragm.* It exerts a certain "suction" upon that muscle, causing it to arch upward in following the contracting lungs. It is seen, therefore, that during inspiration the chest wall and diaphragm exert "suction" upon the lungs, causing them to follow, and during expiration the lungs exert "suction" upon the chest wall and diaphragm, causing them to follow.

Forced Expiration.—It is evident that, while ordinary expiration is a passive process, a person can voluntarily *force* out of his lungs more air than is ordinarily expelled, as in singing, blowing, talking, etc. This is effected by certain muscles whose contraction diminishes the thoracic capacity, chiefly by depressing the ribs and elevating the diaphragm. Those which depress the ribs are the *intercostales interni*, *infracostales* and *triangularis sterni.*. Those which elevate the diaphragm do so by compressing the abdominal contents and forcing them up against that muscle. They are the *obliquus externus*, *obliquus internus transversalis* and *rectus abdominis.* These depress the chest wall as well.

Rhythm of Respiration.—Under ordinary conditions inspiration and expiration follow each other in a regular rhythmical fashion. Some hold that an interval follows inspiration before expiration begins, but this is probably not correct. Indeed, it is doubtful if there be an interval following expiration, though it will be here considered that there is a brief one. Expiration is a little longer than inspiration. The inspiratory act is of uniform intensity throughout, while the expiratory act gradually diminishes in intensity as it approaches completion—a circumstance to be expected from the physical conditions causing it.

After every six to ten respiratory acts a more profound (sighing) inspiration than usual is taken, the effect being a more thorough changing of the pulmonary contents. Coughing, sneezing, hiccoughing, laughing, etc., all interfere with rhythmical respiration.

Modified Respiration.—In *coughing and sneezing* a profound inspiration precedes a violent convulsive contraction of the expiratory muscles. *Sighing* is an expression on the part of the tissues that more oxygen is needed and that, therefore, the contents of the lungs must be more completely changed. *Yawning* is a phenomenon similar to sighing, but may not represent deficient oxygenation, as when it occurs from contagion. Except in the contraction of different facial muscles, *sobbing* and *laughing* are identical from a respiratory standpoint; in both there is a succession of quick contractions of the diaphragm. *Hiccough* is an involuntary contraction of the diaphragm accompanied by closure of the glottis. It takes place during inspiration. In *hawking* the glottis is open and a continuous expiratory current is sent through the narrowed passage between the base of the tongue and the soft palate. *Snoring* occurs with the mouth open; the current of air throws the uvula into vibration and produces the characteristic sounds.

Sounds of Respiration.—When the ear is applied to the chest there is heard during inspiration a breezy expansive sound of slightly increasing intensity throughout, and ceasing abruptly at the end of the act. Immediately begins the expiratory sound, very short, lower in pitch than the inspiratory, and gradually decreasing in intensity until it is lost before expiration is more than one-fourth finished. When listening over a large bronchus this sound is prolonged and has a higher pitch than usual. Respiratory sounds are more pronounced in the female than in the male chest, owing to the predominance of costal breathing in the former sex.

Rate of Respiration.—The respiratory rate sustains a fairly

constant relation to the cardiac rate, the ratio being about one to four. This makes the average number of respirations about *eighteen* per minute for adults. In a general way this rate is subject to variations from the same causes as that of the pulse. Any appreciable fall in the amount of oxygen in the inspired air will increase the number of respirations for obvious reasons. The frequency and depth usually bear an inverse ratio to each other.

Types of Respiration.—(1) **Costal** respiration is that carried on by the chest walls; (2) **diaphragmatic,** that effected by the diaphragm. In the former type movements of the thorax are concerned; in the latter, movements of the abdomen. According as the movements in costal respiration are more pronounced in the upper or lower segment of the chest, that type is subdivided into (*a*) *superior costal* and (*b*) *inferior costal.*

In young children the diaphragmatic, or abdominal, type prevails; in adult males a combination of the inferior costal and abdominal; in adult females the superior costal. The last circumstance is probably due in part to the mode of dress in civilized countries, and in part to the provision against encroachment of the uterus upon the abdominal cavity during pregnancy.

Intrapulmonary and Intrathoracic Pressure.—It is evident that during inspiration the pressure inside the lungs (intrapulmonary) is less than the ordinary atmospheric pressure; this, in fact, is the immediate cause of the entrance of air. It is also evident that during expiration the intrapulmonary pressure, owing to the compressing effect of the lung tissue and the thoracic walls, is greater than the outside atmospheric pressure; this is the immediate cause of the exit of air. In both acts the air rushes in or out, as the case may be, in an effort to maintain the same pressure inside the lungs as exists in the surrounding atmosphere. It is convenient to call the pressure which is less than atmospheric *negative*, and that which is greater *positive* pressure.

The intrapulmonary pressure is negative during *inspiration*

and positive during *expiration.* Now, owing to conditions already referred to, as the chest and lungs expand during inspiration, the pressure between the adjacent walls of the two (intrathoracic) becomes less and less and reaches a minimum at the end of that act. Furthermore, owing to the continuous "pull" of the elastic lungs upon the chest walls the intrathoracic pressure remains negative even at the end of expiration. But it can be made to become positive under forced action of the expiratory muscles, as in coughing, blowing, etc. The constantly increasing negative condition of intrathoracic pressure is evidenced by a drawing in of the intercostal tissues during inspiration; when the pressure assumes a positive character, as in the expiratory acts of the pulmonary emphysema, these tissues bulge outward.

Pulmonary Capacity.—It is evident that the most forcible expiration cannot completely empty the lungs of air. The air remaining after such an effort is the **residual** air. It amounts to about 100 *cubic inches.* But in ordinary respiration at the end of the expiratory act there is more than 100 cubic inches of air in the lungs, because in such cases all the air possible is not forced out. In fact about 200 cubic inches usually remain; this consists of the residual plus another 100 *cubic inches*, which is called the **reserve** or **supplemental** air. It *can* be forced out, but is not in tranquil respiration. The amount of air which is taken into the lungs by an ordinary respiratory act amounts to about 20 *cubic inches*, and is termed **tidal** air. It is the only volume used in quiet breathing. At the end of the inspiratory act in tranquil respiration it is obvious that the expansion may continue still farther, and a certain amount of air, over and above the tidal air, be taken into the lungs. The maximum amount which can be so inspired (beyond the tidal) is about 110 *cubic inches*, and is the **complemental** air.

It is seen, then, that the entire *lung capacity* is equal to about 330 *cubic inches.* But the residual air cannot under any circumstances be called into use, and consequently the *vital capac-*

ity is equal to the total capacity minus the residual air (100 cubic inches), or 230 *cubic inches*. It is the volume which can be expelled by the most forcible expiration after the most forcible inspiration.

The capacity of the trachea and larger bronchi is known as the *bronchial capacity*, and amounts to about 8 *cubic inches*.

The quantity of air in the small bronchioles and air vesicles is increased by inspiration and decreased by expiration; it is called *alveolar capacity*, and at the end of ordinary expiration amounts to about 150 *cubic inches*. Quiet inspiration increases it to about 180 cubic inches.

All these estimates, of course, represent only an average. The vital capacity is increased by stature, by any occupation which calls for active physical work and by various other conditions.

Composition of Air.—Ordinary atmospheric air contains, in round numbers, about 21 parts of oxygen to 79 parts of nitrogen. These two gases make up the main bulk of the atmosphere. In addition, the atmosphere always contains a little carbon dioxide (about .04 per cent.), ammonia, moisture, organic material, dust, nitric acid, etc. All except the oxygen and nitrogen are of minor importance in respiration when they are not present in amounts beyound the usual. It will be seen that the striking difference between inspired and expired air is in the proportions of oxygen and carbon dioxide.

Diffusion in the Lungs.—The expired air contains much more CO_2 and much less O than the inspired air. The interchange of gases between the alveolar air and the blood is responsible for the difference.

The question is what forces cause the O of the air to enter the alveoli and the CO_2 to leave it. As might be supposed, the air escaping during the first part of expiration differs very little in composition from the inspired air, for it has been occupying the upper air passages where no interchange occurs. The bronchial

capacity is only about one-third large enough to accommodate the tidal air, and consequently the greater part of it must come from lower down in the lung structure, and the CO_2 in the expired air continuously increases until the end of the act. At each inspiration at least two-thirds of the tidal air must pass into the small bronchi, or lower. Thus it is that *inspiration* and *expiration* themselves, taking into and bringing out of the vesicles (or at least the bronchioles) air fresh with O and air vitiated with CO_2, aid very materially in keeping constant the composition of the alveolar air.

In the second place, the *cardiac movements* have a similar effect, each systole decreasing the size of the heart and inducing a fresh atmospheric current toward the deep alveoli, and each diastole forcing a like current of vitiated air towards the trachea. This force is not inconsequential.

In the third place, the *diffusibility of gases* under known physical laws, without the aid of any such movements as have been described, is an occurrence in connection with the phenomenon in question. Every gas, under ordinary atmospheric conditions, exerts a certain pressure. In every mechanical mixture of gases (such as the atmosphere) each individual gas exerts a part of the total pressure—a part proportional to its percentage in that mixture. This has been called the "partial pressure" of that gas. Since O is present in ordinary atmosphere to the extent of 21 parts per hundred, the partial pressure of oxygen in the atmosphere is $\frac{21}{100}$ of the total pressure.

Now, in the air of the alveoli O is present to a less extent than 21 parts per hundred, and consequently its partial pressure in that situation is less than in the trachea and bronchi. The result is that O continually makes its way from the point of higher pressure (trachea and bronchi) towards the point of lower pressure (alveoli). The tendency is thus to establish a uniform partial pressure throughout the whole respiratory tract; but this is never done during life because the partial pressure above

is being continually increased by the introduction of new O, and below is being continually diminished by the removal of that gas from the alveoli by the blood.

In case of CO_2 opposite conditions prevail. This gas is being continually introduced into the alveolar air from the blood, and consequently it is present there in much larger quantities than in the trachea and bronchi, which contain newly inspired air. The partial pressure, therefore, of CO_2 in the alveoli is much higher than in the upper respiratory passages, and a continual current of it diffuses upward to equalize the pressure; this is never accomplished, however, for reasons of similar nature to those keeping up the constantly unequal pressure of O.

These three factors—respiratory and cardiac movements and the natural diffusion of gases—are, therefore, in continual operation to get O to and CO_2 away from the alveoli. Under their influence the composition of the alveolar air remains fairly uniform.

Alterations of Air in the Lungs.—These are chiefly: (*a*) Loss of oxygen, (*b*) gain of carbon dioxide, (*c*) elevation of temperature, (*d*) gain of water, (*e*) gain of ammonia, (*f*) gain of organic matter, (*g*) gain of nitrogen, (*h*) loss of (actual) volume. The capital changes are loss of O and gain of CO_2.

(*a*) *Loss of Oxygen.*—The air in passing through the lungs loses of O nearly 5 per cent. of its total volume. That is, whereas on entering it contains 21 parts, on leaving it contains only about 16 parts per hundred of this gas. Nearly 25 per cent. of the total volume of O inspired, therefore, is lost in the lungs.

When the respirations are 18 to the minute, and 20 cu. in. of air are inspired at each breath, the amount inspired in an hour will be 21,600 cu. in. Since a little more than one-fifth of this air is O, and since only one-fourth of the inspired O is consumed, the total amount necessary for an hour will be about 1,100 cu. in. This allows, however, for no muscular, digestive or other activity, and the amount actually necessary is larger than this.

The circumstances which call for an increase in O almost invariably cause an increase in the output of CO_2.

(*b*) *Gain of Carbon Dioxide.*—The amount of CO_2 in inspired air is about .04 part per hundred (4/100 per cent.); the amount in expired air is something more than 4 parts per hundred. In round numbers then, the air in passing through the lungs gains of CO_2 4 per cent. of its entire volume. This is in periods of rest from exercise, digestion, etc. The total amount discharged in one hour is, on an average, about 1,000 cu. in. This estimate should probably be raised to 1,200 cu. in. for ordinary activity, and varies according to many conditions, some of which are rapidity and depth of respiration, age, sex, digestion, diet, sleep, exercise, moisture, temperature, season, integrity of the nerve supply, etc.

The subjoined table from Kirkes' Physiology compares the composition of inspired and expired air.

	Inspired Air.	Expired Air.
Oxygen	20.96 vols. per cent.	16.03 vols. per cent.
Nitrogen	79 " " "	79 " " "
Carbonic acid	0.04 " " "	4.4 " " "
Watery vapor	variable.	saturated.
Temperature	"	that of body (36° C.).

Conditions Influencing Output of CO_2.—When the *rapidity* of respiration is increasing, the depth remaining constant, the percentage of CO_2 in the expired air is reduced because more air is respired, but the total quantity in any given time is increased. The same result follows an increased depth and a constant rate. With a diminished rapidity and increased depth more CO_2 is exhaled than under opposite conditions.

The amount of CO_2 exhaled is small in very *young* infants. But soon the output begins to increase, and in males continues to do so up to about thirty years; there is then a slight decrease up to sixty, and afterward a considerable decrease to death.

In the *female* the output is less than in the *male*. In the former

sex the increase is said to cease at puberty and to remain constant until the menopause, after which time it increases to sixty and diminishes subsequently.

During *digestion* the quantity is considerably increased. This is probably due to the muscular activity of the alimentary tract, to glandular metabolism and to changes taking place in the food products.

As to *diet*, it may be said in general that the exhaled CO_2 is increased in quantity by the taking of nitrogenized foods, tea and coffee.

The influence of *sleep* is to diminish the output.

Muscular *exercise* is very efficient in increasing the amount of CO_2 exhaled; in fact, this explains partly the variations in connection with sex, digestion, sleep, etc.

A high degree of *moisture* increases the exhalation, as does a rise in *body temperature*. A rise in external temperature, however, has an opposite effect.

The output is increased in *spring* and decreased in *autumn*.

When the *efferent nerve* supplying a part is severed the production of CO_2 in that part is at once diminished.

The consumption of O and the exhalation CO_2 bear a fairly constant relation to each other—any condition increasing one increasing the other, and vice versa. The facts, therefore, which have been mentioned as governing the exhalation of CO_2 may be applied to the consumption of O.

(*c*) *Gain in Temperature.*—When the body temperature is normal and the external atmospheric temperature about 70° F., it is found that air inspired through the nose and expired through the mouth has its temperature raised from 70° to about 95°; the rise is less when inspiration takes place through the mouth. The last air of expiration is warmer than the first. This gain of heat while the air is in the lungs needs no explanation when it is remembered that the average temperature of the tissues with which it is in contact is 98.5 F., or higher.

(*d*) *Gain of Water.*—This water is in the form of vapor. It is natural that the air should absorb water from the moist surfaces with which it is in contact. The capillary network with which it is in close relation supplies moisture to the mucous membrane not only of the alveoli but of the entire respiratory tract. One or two pounds of water are eliminated thus daily.

(*e*) *Gain of Ammonia.*—Ammonia is exhaled in small quantity by the lungs. It is insignificant except in cases of suppressed kidney action.

(*f*) *Gain of Organic Matter.*—The quantity of organic matter exhaled by the lungs is inconsequential (unless ventilation be bad), but such exhalation does occur to a small extent. It gives the odor to the breath.

(*g*) *Gain of Nitrogen.*—The exhalation of this gas by the lungs is of no respiratory importance. The amount is said to be $\frac{1}{100}$–$\frac{1}{50}$ the amount of oxygen consumed. An occasional loss of nitrogen has been observed.

(*h*) *Decrease of (Actual) Volume.*—When the external temperature is below about 90° F. the volume of expired air is a little greater than that of the inspired air, because of the increase of temperature it undergoes in passing through the lungs. But the *actual* volume of the expired air, when reduced to the same temperature as the inspired, is found to be always a little less than that of the latter. It is estimated that from $\frac{1}{70}$–$\frac{1}{50}$ of the total volume of the inspiried air is thus lost in respiration.

Besides the substances mentioned as being exhaled from the lungs, it is well known that odorous emanations proceed from them after garlic, onions, turpentine, alcohol, certain drugs, etc., have been taken into the stomach.

Relation Between Oxygen Consumed and Carbon Dioxide Exhaled.—A given volume of O will combine with carbon to form the same volume of CO_2; or the amount of O in a given volume of CO_2 is equivalent to that volume when set free from the carbon. A cubic foot of O will unite with carbon to form

a cubic foot of CO_2; or a cubic foot of CO_2 will yield, on dissociation, a cubic foot of O.

This being the case, if all the O consumed in the lungs were exhaled therefrom in the form of CO_2, the amount of CO_2 exhaled would just equal the amount of O consumed. But the amount of consumed O is about 5 per cent. of the inspired air, while the amount of exhaled CO_2 is only about 4 per cent. of the expired air. It follows, therefore, that 1 per cent. of the volume of inspired air is not represented by the CO_2 exhaled from the lungs and skin. The relation between the consumed O and the exhaled CO_2 is usually expressed as the "respiratory quotient"—the division of the latter by the former giving the quotient. This quotient is made to vary by many circumstances, though for any considerable period its average is about the same.

While it has been stated that the O absorbed and the CO_2 produced vary together usually, they are in a certain measure independent of each other. For CO_2 does not result from the immediate union of O with carbon of the carbohydrates and fats, but may be stored in the shape of complex compounds, which may later split up with the formation of CO_2, either by oxidation or by intramolecular cleavage. Furthermore, more O is necessary to oxidize (that is, to form carbon dioxide) some molecules than others. A fat requires considerably more O to produce CO_2 than does a carbohydrate; so that the kind of food in store would also affect the respiratory quotient.

With respect to the O which, in the long run, is not represented in the CO_2 exhaled from the lungs and skin, it is certain that when various of the food-stuffs are broken down at least a part of it is appropriated by hydrogen to form water.

Source of Exhaled Carbon Dioxide.—The increase of CO_2 in expired air over the small amount contained in inspired air is derived from the *venous blood* circulating through the lungs. It exists in that blood under a constant tension, as is demonstrated by its escape when the blood is placed in a vacuum. The total

amount escapes when the blood intact is placed *in vacuo:* when the corpuscles alone are so treated they yield up all their CO_2, though it is small in amount; but the plasma alone *in vacuo* yields a less amount than when it contains corpuscles. If, now, corpuscles be added to the plasma the total amount of CO_2 is forthcoming. The corpuscles must, therefore, act as an acid causing the liberation of this gas from the plasma. It is probably the hemoglobin, or oxyhemoglobin, which has this effect, though in the laboratory the phosphates and certain proteids of the corpuscles produce a like reaction when brought in contact with the carbonates and bicarbonates of soda.

Condition of CO_2 in the Blood.—About 5 per cent. of the total amount of CO_2 in venous blood is in *simple solution* in the plasma; about 75–85 per cent. is in loose *chemical combination* in both corpuscles and plasma; the remaining 10–20 per cent. is in *comparatively stable combination* in the plasma. Of the 75–85 per cent., by far the largest part is in the plasma, probably in a condition of loose association with sodium to form carbonates and bicarbonates; the small part in the corpuscles may exist in a similar state, but it is now thought to exist in combination with the proteid portion of hemoglobin. The total 75–85 per cent. in corpuscles and plasma is so loosely combined that the mere diminution in pressure in the lungs is probably sufficient to liberate it. The 10–20 per cent. in firm chemical combination is that part which cannot be extracted from plasma alone *in vacuo*, but which is dissociated on the addition of an acid, or corpuscles, or hemoglobin, etc. It may be that as the blood passes through the lungs there is set free, in the formation of oxyhemoglobin, an acid which immediately unites with the bases holding the CO_2 in combination—the liberation of the latter being the consequence.

The O being thus in the air vesicles, and the CO_2 thus free, or set free, in the blood, with the very thin animal membrane consisting of the vesicular and capillary walls between them, it re-

mains to be seen what forces are concerned in the interchange of these gases. It has been noted that only one-fourth of the O entering the lungs in the air is taken up by the blood; so it is to be remembered that not all the CO_2 entering the lungs in the venous blood is taken up by the air.

Interchange of Oxygen and Carbon Dioxide in the Lungs.—The condition of "partial pressure" of gases in mixture has been mentioned, Each gas exerts a pressure in proportion to its percentage in the mixture, and this is called its "partial pressure." Now, the extraction of O and CO_2 from the blood by placing it in a vacuum shows that both these gases exist in the blood under a certain degree of tension.

The tension of a gas in solution being only the pressure necessary to keep it in solution, it follows that if the pressure be diminished the gas will partly escape. If an atmosphere containing, say, O at a certain partial pressure be brought in contact with a fluid containing O at a certain tension, unless the partial pressure of the O in the air be equal to its tension in the fluid there will be an escape of the gas from the point of higher to the point of lower pressure or tension. If the partial pressure of the gas be less in the atmosphere than its tension in the fluid, the current will be from the latter to the former and vice versa. This will be the case whether the media are in actual contact or separated by an animal membrane.

This is the condition which obtains in the pulmonary alveoli. The partial pressure of O in the alveolar air is much greater than the tension of O in the blood; consequently the current is from the air to the blood. The tension of CO_2 in the venous blood is much greater than the partial pressure of the CO_2 in the alveolar air; consequently the current is from the blood to the air.

But, here, as in the last analysis of almost all physiological phenomena, it is found that, while these purely physical laws are certainly concerned in the pulmonary interchange of gases,

they are insufficient to explain the occurrences in full. For the blood will take from the alveolar air more than enough O to establish an equilibrium of tension and partial pressure; the tension of O in arterial blood is higher than its partial pressure in alveolar air. So it is found that the alveolar air will remove more than enough CO_2 to establish a similar equilibrium of this gas. It is known that the avidity (chemical) of corpuscles for O to form oxyhemoglobin causes the blood to appropriate more O than it would otherwise do, but even then we are driven to the usual ultimatum of ascribing some peculiar office to the living epithelium of the intervening membrane.

Condition of Oxygen in the Blood.—Almost all the oxygen is conveyed in the blood by the red corpuscles, where it exists in rather unstable composition with hemoglobin (probably with its pigment portion) under the name of *oxyhemoglobin.* Only a comparatively small part is held in solution by the plasma. Dissociation of oxyhemoglobin occurs when the pressure is sufficiently reduced.

Alterations in Blood in Passing Through the Lungs.—The sum total of the changes taking place in the blood as it passes through the lungs is represented by the term *arterialization.* In general, it may be said that the blood undergoes changes *exactly opposite to those of the air* in circulating through the pulmonary structure, and reference to the list of substances gained and lost by the air will suggest the main alterations in the blood.

Of course the most striking phenomena are the *loss of* CO_2 *and the gain of O.* In 100 volumes of arterial or venous blood there are found to be, on an average, 60 volumes of O and CO_2. This total remains approximately constant, though the relative amount of each gas varies according as the blood is venous or arterial, and in venous blood under the influence of several conditions to be mentioned. In arterial blood the O will represent about 20, and the CO_2 about 40, of the total 60 volumes per hundred of gas. In ordinary venous blood the O will represent

about 7 volumes less (13) and the CO_2 about 7 volumes more (47) of the total 60. In both venous and arterial blood there is an insignificant amount of nitrogen, which is usually present to the extent of 1.5 volumes per hundred.

The proportion of gases is about the same in arterial blood taken from any part of the system. In blood coming from actively secreting glands the ratio of O to CO_2 is nearly the same as in arterial blood; in fact, such blood may have a red (arterial) instead of a blue (venous) color. This is because during activity blood is sent to the gland in increased amount to furnish materials for secretion, while the demand for oxygen is not relatively increased in that gland.

Besides the changes which are apparent on referring to the alterations in the air in passing through the lungs, there are certain other general characteristics which distinguish arterial from venous blood. The most noticeable is *color*. Venous blood is changed in the lesser circulation from a dark blue, or black, to a bright red. This is due to the formation of oxyhemoglobin. The change of color does not occur when the appropriation of O is interfered with, as when air is excluded from the lungs, or when carbon monoxide is inhaled. Again, there is every reason to believe that venous blood coming from different organs differs in composition according to the *special materials* which have been extracted from it by those organs; the portal blood during digestion must certainly be different in composition from the general venous blood, and so it may be conceived that the blood coming from no two different sets of capillaries is identical. When all this meets in the right side of the heart and is sent thence into the lungs it has a nearly uniform composition, and needs only to receive O before it can supply the wants of any particular tissue in the body. Arterial blood is also more *coagulable* than venous.

Internal Respiration.—It has been said that the object of external respiration and the transportation of O and CO_2 is to make internal respiration possible. Oxygen, leaving the alveoli

in a manner already described, enters the blood and at once combines with hemoglobin of the red corpuscles to form *oxyhemoglobin*. A small portion of the O is *used up by the corpuscles* in transit, with the production of CO_2 and other metabolic materials— the corpuscles requiring O in their metabolism just as do other cells. But by far the largest portion is carried to the capillaries, where it is taken up by the cells. At the same time the cells give up to the blood CO_2—a result of their metabolic activity. The blood, having thus given up its O, is changed in color, and carries the CO_2 back to the lungs to be exhaled.

To furnish O and to remove CO_2 is the only object of respiration. Living tissue exposed to an atmosphere containing O will consume O and exhale CO_2 even if no blood be circulating through it. The exact manner in which a cell uses O is not apparent. It is evidently an oxidation process which produces CO_2, and O is directly necessary to this process. But the amount of CO_2 produced in any given time may not correspond to the amount of O consumed in that time; it may be greater or less. "It is probable that during rest O is utilized to some extent in oxidations which are not at once carried to their final stage and in which relatively little CO_2 is formed; hence during activity comparatively little O is required to cause a final disintegration of the now partially broken down substances, and thus to give rise to a relatively large formation of CO_2" (Reichert).

The absorption of O is to be looked upon as a part of the nutritive process just as the absorption of proteid, *e. g.*, and CO_2 as one of the products of destructive metabolism just as urea. There is small probability that the O unites *directly* with the carbon of any of the food stuffs—although this is the final result.

Interchange of Oxygen and Carbon Dioxide in the Tissues.—Here application of the principles governing the interchange of these gases in the lungs applies. It is found that the tissues act as very strong reducing agents upon oxyhemo-

globin, setting free the O. Now the tension of O in the arterial capillaries is much higher than in the tissues; in fact, it is practically nothing in the latter situation, for the O enters so quickly into combination that there is very little to be found here at any time. Consequently physical laws encourage the passage of this gas out of the capillaries into the tissue.

On the other hand, the tension of CO_2 in the tissues is much higher than in the blood, and the same physical laws encourage a current of CO_2 towards the blood. Nevertheless, these laws do not explain all the phenomena of interchange; the activity of the cells is an important agent, though their influence may be of a chemical nature only.

Cutaneous Respiration.—Cutaneous respiration in man is insignificant and not essential to life. The skin absorbs a little O and exhales a little more CO_2. It is estimated by Scharling that the skin performs about $\frac{1}{60}$ of the respiratory function. Death following the covering of the body surface with an impermeable coating is not due to interference with cutaneous respiration.

Ventilation.—Persons breathing in a confined space gradually consume the O and increase the CO_2 of the atmosphere. When the amount of O has been decreased to *fifteen parts per hundred* it is insufficient for the respiratory demands. When the CO_2 is increased to .07 *part per hundred* the air becomes disagreeable and close; this is not, however, from the accumulation of CO_2 so much as from organic emanations and disagreeable odors from the body, clothing, etc. It is only that the amount of CO_2 serves as an *indication* of the extent of accumulation of these materials that the amount .07 per cent. is fixed as the limit beyond which it ought not to be present. This percentage of CO_2 in air free from emanations, etc., is not deleterious.

Since 1,200 cu. in. of O are consumed per hour, about 15 cu. ft. will be necessary for a day; and since the 1,200 cu. in. consumed represent only about one-fourth of the O inspired, 60 cu. ft. will be necessary for inspiration during twenty-four hours.

This amount represents some 300 cu. ft. of atmospheric air—which an ordinary person must have in that time.

But this estimate allows nothing for increased respiratory activity, which inevitably occurs from some of the numerous conditions influencing it. It is found that in prisons and other institutions of confinement it is not safe to allow each person less than 1,000 cu. ft. of atmospheric air. In crowded houses, where this space per individual cannot be obtained, it is necessary, in order to avoid unpleasant results, to change the air continuously, or at frequent intervals. Natural and artificial means are employed to accomplish this end.

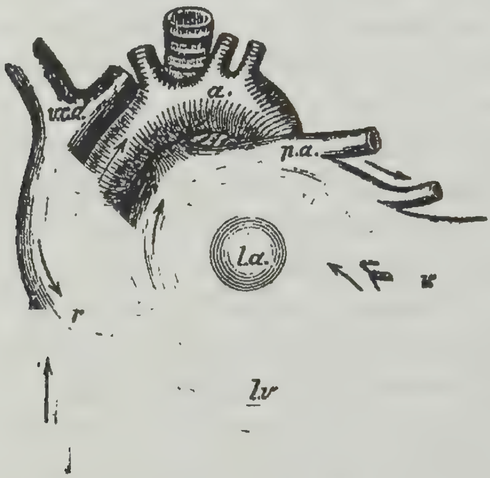
Respiration of Various Gases.—The inhalation of pure *oxygen* is not deleterious unless it be under higher tension than in atmospheric air, when it becomes a local irritant. The blood will not, however, appropriate more than the usual amount. *Nitrous oxide* will sustain respiration for a time, but soon produces unconsciousness and asphyxia, probably because it unites so firmly with the hemoglobin of the corpuscles. *Hydrogen* may be inhaled with impunity if it contain also oxygen in the atmospheric proportion. *Carbon monoxide* is poisonous because it unites with hemoglobin to the exclusion of oxygen and will not dissociate itself. *Sulphurretted*, *phosphoretted* and *arseniuretted hydrogen* are destructive of hemoglobin and consequently poisonous. Pure *carbon dioxide* cannot be inhaled for any length of time.

Abnormal Respiration.—The term *eupnea* is used to describe normal, tranquil breathing, *Apnea* is suspended respiration. *Hyperpnea* is exaggerated respiration. *Dyspnea* is labored breathing. *Asphyxia* is essentially a want of O characterized by convulsive respirations, and later by irregular shallow breathing. The last two named deserve some attention.

Dyspnea may be due to either a deficiency of O or an excess of CO_2 in the blood. When an animal is made to breath in a small, confined space the amount of O soon becomes insufficient,

even though the amount of CO_2 in the blood be not increased. Again, if an animal be caused to breathe air containing the usual amount of O and a large amount of CO_2, it will suffer from dyspnea also. In either case the manifestations are practically the same—slow, deep and labored respiration. In cardiac disease, hemorrhage, pulmonary diseases, etc., the dyspnea is from a lack of O in the tissues, because of enfeebled action of the heart,

FIG. 42.



The heart in the first stage of asphyxia.

The left cavities are seen to be distended; the left ventricle partly overlaps the right; *l.a*, left auricle; *l.v*, left ventricle; *a*, aorta; *p.a*, pulmonary artery; *p.v*, pulmonary vein; *r.a*, right auricle; *r.v*, right ventricle; *v.c.d*, descending vena cava; *v.c.a*, ascending vena cava. (*Kirkes* after *Sir George Johnson.*)

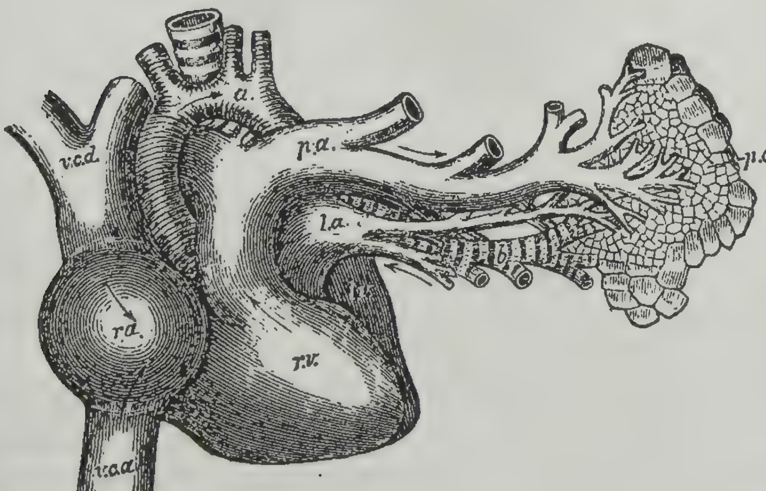
deficient quantity of blood, insufficient exposure of the blood in the lungs, etc.

Asphyxia may be looked upon as exaggerated dyspnea. The labored breathing of dyspnea becomes convulsive, and finally collapse ensues. Respiration becomes shallow, consciousness is lost, the pupils are dilated, opisthotonus develops, the reflexes disappear, and at last the heart stops beating. The skin and mucous membranes become blue from non-oxygenation of

the blood. Asphyxia from submersion is harder to overcome than from simple deprivation of air outside the water. Resuscitation is extremely doubtful when a person has been submerged as long as five minutes.

While the phenomena of dyspnea and asphyxia are referable to the lungs, it is not the need of air in these organs, but of O in the tissues, which gives rise to the symptoms. The non-oxygenated blood in asphyxia will not circulate through the capillaries except with the greatest difficulty, and the result is that it accumulates in the arterial system, dams back upon and distends the

FIG. 43.



The heart in the final stage of asphyxia.

The letters have the same meaning as in Fig. 42; in addition, *p.c*, represents the pulmonary capillaries. The right auricle and ventricle, and the pulmonary artery, are fully distended, while the left cavities of the heart and the aorta are nearly empty. *Kirkes* after *Sir George Johnson.*)

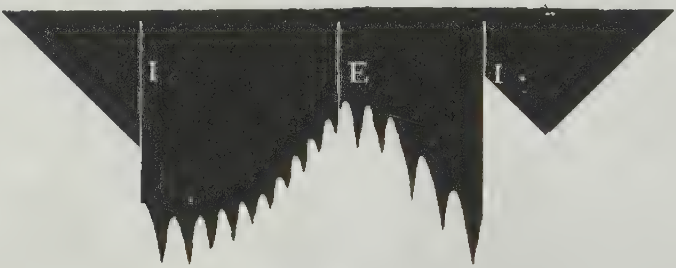
heart, so that this organ is finally paralyzed and ceases to beat. This is the cause of death from asphyxia.

Effect of Respiration on Blood-Pressure.—The lowest blood-pressure is just after the beginning of inspiration, from which time it increases during inspiration to reach its maximum

just after the beginning of expiration; it gradually decreases from this time to the minimum just after the beginning of inspiration. The general effect, then, of inspiration is to *increase* blood-pressure and of expiration to *decrease* it. This remark applies to general arterial tension.

Taking **inspiration,** the increase in arterial tension is, in its last analysis, due to the *larger amount of blood sent into the arterial system at each ventricular systole.* The explanation is some-

FIG. 44.



Carotid blood-pressure tracing of dog.
Vagi not divided; I, inspiration; E, expiration. (*Stirling.*)

what complex, but if the mechanics of respiration be understood it may be made satisfactory.

It was seen that the lungs are contained in an air-tight cavity, the chest, and that they expand with the chest because of negative pressure ("suction") exerted upon them. The heart is also a hollow organ situated in this cavity; it has connected with it, and lying also in the thoracic cavity, large vessels communicating with smaller extrathoracic vessels. The heart and these great thoracic vessels are elastic and distensible. Consequently the expansion of the thorax also expands them slightly and tends to draw blood from the extrathoracic into the intrathoracic vessels and heart; in fact inspiration is one of the main forces causing a flow of venous blood towards the heart. Now all this, so far as it goes, tends to keep the blood out of the extrathoracic

vessels, and so to contradict the statement that inspiration increases arterial tension.

But, remembering that we are dealing with *arterial* tension and that our effort is to prove that more blood is sent into the aorta during inspiration than during expiration, it is of value to note that since the walls of the aorta are more resistant than those of the venæ cavæ there is less expansion of the former than of the latter during inspiration, and consequently less *tendency* for the arterial blood to regurgitate into the thoracic aorta than for the venous blood to enter the thoracic venæ cavæ. The same expanding force dilates the pulmonary capillaries, pulmonary artery and pulmonary veins—the artery least of these. Taking it for granted that more blood is being received by the right side of the heart from the incoming venæ cavæ, the somewhat dilated pulmonary artery receives more from the right ventricle; the pulmonary capillaries are more dilated than the artery and this fact greatly encourages (by a suggestive "suction") the increased flow from the pulmonary artery; they, therefore, receive more blood than usual. The pulmonary veins, being likewise dilated, exert "suction" upon the capillaries, and thus receive and pass on to the heart a larger supply of blood than usual. The heart, receiving more blood, must send more into the aorta, thereby increasing arterial tension in the extrathoracic vessels, *unless, by expansion of the chest, the thoracic aorta be so dilated as to accommodate the increased amount*—which is not true.

Then, finally, the validity of this argument will hinge on the relative dilatation of the thoracic aorta and of the thoracic venæ cavæ. If the veins be less dilated by inspiration than the artery, then they will receive an increase of blood which will not completely occupy the increase of space in the dilated thoracic aorta, and there will be a backward "suction" made upon the contents of the arterial tree with a consequent decrease in pressure; but a condition just opposite to this seems to obtain.

During **expiration** contrary conditions in general are opera-

tive with contrary results. The intrapulmonary vessels and heart are compressed, but the veins and capillaries more than the aorta, with the result that less blood reaches the heart than during inspiration, and the thoracic aorta being, relatively to the thoracic venæ cavæ, more dilated now than during inspiration can easily accommodate the decreased amount of blood which it receives. Of course expiration increases venous pressure in the veins which enter the thorax back as far as the valves.

The reason the pressure does not rise with the *beginning* of inspiration is because a short time is consumed in filling the flaccid intrapulmonary veins, and the first increase of blood is delayed for that purpose instead of passing on to the left side of the heart. Similarly, the pressure continues to rise for a short time after expiration has begun because the large veins are being emptied by pressure during this time and their contents are reaching the heart and being forced into the aorta.

Movements of the diaphragm and abdominal muscles during respiration also lend themselves to create like changes in arterial pressure, but the main factors are intrathoracic.

The fact that the cardiac rate is increased during inspiration and decreased during expiration may also have to do with the variations in pressure.

All the foregoing remarks relative to arterial tension are meant to apply to tranquil respiration. During forced inspiration, or forced expiration, the results may be modified, or even reversed, by circumstances not necessary to mention.

Nervous Mechanism of Respiration.—Although the muscles of respiration are of the striated variety, it is by no effort of the will that the movements are kept up. They belong to the class known as automatic; that is, they are, up to certain limits, under the control of the will, but recur in a regular, coördinate and orderly manner without the active intervention of volition. Respiration represents the activity of a self-governing apparatus. These movements constitute a finely coördinated set of contrac-

tions—contractions which are regulated by means of afferent and efferent nerves under the supervision of the respiratory center.

The **respiratory center** is in the lower part of the medulla oblongata. Destruction of the encephalon above, or the cord below, the center does not arrest respiration. It is bilateral—a center for each side—and these are more or less independent of each other, but are so intimately connected by commissural fibers that any impression made upon one usually produces a like effect upon the other. Each half presides over the lungs and respiratory muscles of its own side, but acts synchronously with its fellow of the opposite side. Furthermore, each of these lateral centers may be regarded as consisting of two parts, one for inspiration and one for expiration. Stimulation of the inspiratory center not only strengthens the inspiratory act, but also accelerates respiration. Stimulation of the expiratory center strengthens expiration and also retards the respiratory rate. The accelerator portion of the center seems more sensitive than the inhibitory, and the result of stimulation of the whole center is therefore quickened respiration.

Subsidiary respiratory centers are said to exist in the tuber cinereum, optic thalamus, corpora quadrigemina, pons Varolii and spinal cord; but the existence of at least some of these is doubtful.

Rhythm of Respiration.—What agency excites the center to keep up the respiratory movements with such regularity is a matter of interest. The chief circumstances which seem to affect the rate and rhythm are (1) *the will*, (2) *emotions*, (3) *composition of the blood* and (4) *afferent impressions.*

1, 2. The effect of the will and emotions are too apparent to call for comment. 1 and 2 are properly included in 4.

3. A deficiency of O or an excess of CO_2 in the blood will increase the rate. Increase in temperature of the blood, as in fever, will produce a similar effect.

4. The most important of these agencies is found in afferent

impressions conveyed to the center. The fibers carrying these impressions are chiefly in the *pneumogastric*, *glosso-pharyngeal*, *trigeminal* and *cutaneous* nerves. Of these the pneumogastric is by far the most important.

Section of a single pneumogastric is followed by variable respiratory disturbances which usually disappear in less than an hour. Section of both nerves is followed, after a short interval of increased respiratory activity, by slow and powerful inspirations, by forced expiration and an appreciable interval before the next inspiration. Irritation of the central end of the cut nerve by a very weak current seems to stimulate the inhibitory part of the center, for the rate is slowed, the expirations are strenuous and the inspirations weak. When the current is increased to a moderate strength opposite results are obtained, the accelerator portion of the center being stimulated. These facts show that the pneumogastrics possess both inspiratory and expiratory fibers, and that the former are stimulated more by a moderate current and the latter more by a very weak one. The rhythm of respiration, therefore, includes the regular sequence of inspiratory and expiratory movements upon each other.

Now what is it that, under normal conditions, irritates the terminals of the pneumogastrics and causes them to convey inspiratory and expiratory impressions? It has been held that a *change in the composition of the alveolar air*—an accumulation of carbon dioxide—irritates the nerve terminals and explains the conveyance of the inspiratory impressions, while the *stretching of the lung tissue* originates the expiratory impressions. Others ascribe both inspiratory and expiratory impressions to *lung movements*—movements of inspiration exciting expiratory fibers, and movements of expiration exciting inspiratory fibers. These observers cite the fact that artificial inflation and aspiration excite expiration and inspiration respectively.

Stimulation of the *superior laryngeal*, as when foreign bodies accidentally enter the larynx, excites violent expiration.

The *glosso-pharyngeal* contains afferent fibers especially important in arresting respiration—at any stage whatever—during the act of deglutition.

Stimulation of the sensory fibers of the *trigeminal* in the nose, as by irritating vapors, may arrest respiration.

Irritation of the *cutaneous* nerves in general, as by cold or hot water, slapping, etc., stimulates respiratory movement.

There are, of course, running from the cortex to the respiratory center *intracranial fibers* whereby the organ of the will makes its presence felt in respiration.

But when all the afferent nerve connections are severed, respiration continues with modified rhythm and rate, at least for a time. It is thought that, under these conditions, it is the circulation through the center of *blood deficient in oxygen* which causes the cells to discharge; that is, after every inspiration and subsequent expiration there is not another inspiration until the blood has become sufficiently deoxygenated, or charged with carbon dioxide, to *irritate the respiratory center.*

We may conclude that "the rhythmical discharges from the center are due primarily to an inherent quality of periodic activity of the nerve cells constituting the respiratory center, and maintained by the blood, and that the rhythm, rate, and other characters of these discharges may be affected by the will and the emotions, by the composition, supply and temperature of the blood, and by various afferent impulses. The chief factors are the quantities of O and CO_2 in the blood, and the impulses conveyed from the lungs by the fibers of the pneumogastric nerves." (Am. Text-Book.)

The *efferent nerves* of respiration control the muscular movements of that act. They are chiefly the *facial, hypoglossal and spinal accessory* controlling the respiratory movements about the face and throat; the *pneumogastric* going to the larynx; the *phrenic* to the diaphragm; certain of the *spinal nerves.*

To the lungs proper fibers are distributed by the *vagus*, the

dorsal spinal and the *sympathetic* nerves. Besides the expiratory and inspiratory fibers already noticed, the vagus supplies the lungs with broncho-motor, general sensory, trophic and secretory (mucous) fibers. The sympathetic furnishes trophic and vaso-motor fibers, which latter come from the cord by the roots of the dorsal nerves mentioned to join the sympathetic ganglia.

CHAPTER VII.

FOODS, DIGESTION AND ABSORPTION.

(A) FOODS.

It is evident that all the tissues of the body are continually undergoing "physiological wear"—that the materials of which they are intrinsically composed are being changed into effete matter and discharged from the system. This is a process going on in the substance of every cell in the body, and obviously for these cells to continue to live and functionate there must be a continual appropriation of new matter to take the place of the materials which have served their physiological purpose, and are therefore now useless. Such supply is made directly to the tissues by the blood, but lest this fluid be improvished, it must in turn be furnished with an approximately constant quantity of nutritive matter. The ultimate source of that matter is in the food we eat, though of course it must pass through the processes of digestion and absorption. This conception of a food must be understood to embrace all substances contributing, either directly or indirectly, to body nutrition, including, therefore, the oxygen of the air as well as all articles usually classed as drinks.

An animal whose weight remains about the same must eat and digest a certain quantity of food to keep up the body temperature, to supply mechanical energy, and to repair the wastes which go on even during sleep. An animal which is growing and increasing in weight must eat enough not only to supply the demands just mentioned, but also to be stored up as new tissue when prop-

erly transformed. It will be seen that the articles we eat, besides being largely insoluble, differ very materially in their composition from any substances found as parts of the body tissues, and also that even those undigested substances most closely resembling living tissue will not be utilized by the cells when presented to them (injected) in the usual vehicle, the blood.

Seat of Hunger.—Food is taken into the body in obedience to an expressed want on the part of the system. The desire for food—the sensation of hunger—is referred in a rather indefinite way to the stomach. But because that sensation is ordinarily satisfied by the introduction of food into the stomach does not argue that its seat is in that organ. Removal of the stomach by no means prevents hunger, but if nutritious materials be introduced in sufficient quantity into the circulation, as by rectal enemata, hunger is relieved. The true seat of this sensation is undoubtedly in the cells themselves, it being simply a call from them for more material to take the place of their worn-out constituents.

Cold weather demands an increase in the amount of food, as also do physical and psychical activity, certain drugs, etc.

Seat of Thirst.—The demand of the cells for water is referred to the fauces and throat, but this is no more the seat of thirst than is the stomach of hunger. The taking of water into the mouth alone will not quench thirst, except in so far as absorption may take place from the mucous membrane. But if water in sufficient amount be gotten into the circulation in any way satisfaction ensues. Next to the demand for oxygen, that for water is the most imperative which comes from the tissues; that is, they can live much longer without solid food than without water. The amount necessary is manifestly subject to many conditions, such as external moisture and temperature, exercise, etc.

Classification of Foods.—A very large number of substances are taken into the alimentary canal as food; but examination

reveals that all such materials contain one or more of a very few *classes* of alimentary principles or food stuffs. The foods are classed as:

I. **Salts and Water.**—Compounds yielding no energy.

II. **Proteids, Albuminoids** (nitrogenous).	Compounds yielding energy.
III. **Carbohydrates** (non-nitrogenous).	
IV. **Fats** (non-nitrogenous).	

I. The **salts** and **water** are scarcely looked upon as food in the common acceptation of the term, but they are quite as necessary to cell life as any of the other classes. They constitute an unimportant factor in the process of digestion and receive little attention in a discussion of that subject, because they really do not undergo digestion at all, but are simply dissolved in the fluids of the alimentary tract, absorbed and discharged from the system in the same shape in which they entered. Such as cannot be dissolved in the gastro-intestinal media are never absorbed. It is evident that much of this class is ingested with II, III and IV. In fact, all the proteids have combined with them materials, from which they are not separated by digestion; the two are deposited and discharged together from the system. Suffice it to say, that excepting water and common salt, our ordinary foods furnish a supply of the compounds yielding no energy.

II. The **proteids,** are of different varieties, but all are of approximately the same food value, and indeed cannot be studied separately. They are contained in both animal and vegetable diets, but usually the main part of our proteid income is in meat. They are the most important of the food stuffs because they are the only ones *containing nitrogen*, and they are therefore the only ones capable of repairing tissue wastes or building up new tissue. Under the consideration of Nutrition it will be seen that the proteids, besides being useful in constructive metabolism, are also of value in furnishing bodily energy and heat. It is unnecessary to add that this is the only class of foods capable alone of sustaining life, for vital activity means protoplasm, and protoplasm is

nitrogenous in composition. Proteid is an absolute necessity; the other foods are only accessory to this class.

Special attention is called to the fact that while the **Albuminoids** are not here differentiated from the proteids, they properly belong in a class by themselves. They contain nitrogen and therefore resemble the proteids in chemical composition, but they are incapable alone of sustaining life, and therefore resemble the carbohydrates and fats in their physiological value. Gelatin is a typical example of the albuminoids. As a class they do not exist to any considerable extent in the articles we eat, and in this work the terms "nitrogenous" and "proteid" foods will be considered synonymous, and the true albuminoids will be largely disregarded.

III. The **carbohydrates,** include the starches, sugars, gums, etc., already referred to. They are of definite chemical composition and *contain no nitrogen.* They are contained in fruits, vegetables, especially in cereals, and in some animal foods, such as milk, honey, liver, etc. They are the cheapest foods from financial and digestive standpoints and constitute the main bulk of articles eaten. They contain more oxygen than do the fats, and are more easily oxidized and converted into heat and muscular energy. In fact, their great physiological value lies in the ease with which they are thus burned up in the body. They furnish the main part of the fuel necessary to the running of the animal mechanism.

IV. The **fats** are ingested with both animal and vegetable diets. Animal fat, seeds, grains, nuts and certain fruits and cereals furnish in most part this class of our foods. The fats *contain no nitrogen*, and, like carbohydrates, their great physiological value lies in the fact that they are destroyed in the organism to produce energy, whether in the form of heat or muscular exercise. They are handled and converted less readily by the system than the carbohydrates, and consequently tax the digestive powers more. But it is found that, weight for weight, they are

more efficient in the production of energy than are the carbohydrates. They also furnish fuel for the running of the body mechanism. How the reserve energy of the body is stored up in fat will receive later notice.

Now, the articles we ordinarily take as food contain usually all the above classes, together with innutritious and indigestible materials from which they must be separated. The animal foods, particularly eggs and the muscular substance, are characterized by the small amount of carbohydrate and the large amount of proteid substance entering into their composition. Of the meats, beef especially contains much proteid. As a rule vegetables contain much carbohydrate, but also quite a quantity of proteid matter. Peas, beans, etc., contain much proteid. But it is not to be forgotten that nutrition is effected not by what is eaten but by what is *absorbed*. It is found that the animal proteid foods are usually more completely digested and absorbed than are the vegetable.

(For amount and kind of food necessary see Nutrition.)

(B) DIGESTION.

Object.—Digestion is largely a *chemical* process. Certain *physical* phenomena are auxiliary. The foods not yielding energy are not affected in a chemical way by digestion. They are simply dissolved, if not already in solution, and are discharged from the body in the same condition in which they entered. But the other classes of food must either be separated from innutritious substances with which they enter, or undergo certain changes themselves, or both, before they can be absorbed and assimilated. This necessitates a complicated digestive apparatus and the subjecting of different classes of food to different digestive fluids and other gastro-intestinal influences. The object of digestion is therefore twofold, *first*, to convert the foods into soluble materials and, *second*, to bring about such changes in their composition as will insure their absorption and appropriation by the tissues.

Enzymes.—The chemical changes taking place in digestion are of a peculiar nature, in that they are effected largely by the presence of substances known as **enzymes,** corresponding in an obscure way with ordinary chemical reagents. These have been called **unorganized** or **unformed ferments,** to distinguish them from such **organized ferments** as bacteria, yeast, fungi, etc. They are not themselves possessed of any vital activity, though formed in living organisms, like plants or animals. They are of indefinite chemical composition, contain nitrogen and are supposed to be of proteid structure. The characteristic point in their action has been supposed to be that they *produce a chemical change without themselves being affected by that change.* This is doubtless *practically* true, but it is found in experimental work that "a given solution of enzyme cannot be used over and over again indefinitely." It finally loses its identity.

According to the foods on which they act and the effects they produce, enzymes are classified as: (1) **Proteolytic enzymes.** These convert proteids into soluble peptones; examples are *pepsin and trypsin.* (2) **Amylolytic enzymes.** These convert starches into sugar; examples are ptyalin and amylopsin. (3) **Fatsplitting enzymes.** These convert neutral fats into glycerine and fatty acids; an example is steapsin. (4) **Sugarsplitting enzymes.** These convert the non-absorbable (saccharose) into absorbable (dextrose) sugar; an example is invertase. (5) **Coagulating enzymes.** These precipitate soluble proteids; an example is rennin.

Characteristics of Enzymes.—Some of the characteristics of enzymes are as follows: (1) They are soluble in water and in glycerine. (2) In solution they are destroyed before the boiling point is reached (140° to 180° Fahrenheit). Very low temperatures do not destroy them, but suspend their action. (3) They never completely convert the substance upon which they act (unless it be the fifth class). It is supposed that the substance produced, as peptones for example, have an inhibitory

action upon the enzyme. If they are removed as they are formed, the action of the enzyme continues. (4) The particular result is independent of the *amount* of the enzyme (unless it be very small) no matter how large a quantity of the substance to be acted upon is present.

Manner of Action.—These enzymes are supposed to bring about their respective changes through *hydrolysis*—that is, by causing water to be taken up by the molecules of the affected substance and by the subsequent splitting of the newly formed molecule into two or more simpler ones. How they cause this appropriation of water is as yet undetermined. It was formerly supposed to be brought about by *contact* merely, and the enzymes were called *catalytics;* but this term offers no explanation of the real change which occurs.

This much seems necessary to be said about enzymes, that a more intelligent understanding may be had of the part they play in digestion. The facts in regard to them as above enumerated are gathered mainly from Howell.

Digestive Processes.—The digestive processes may be considered under the heads of (1) *prehension*, (2) *mastication*, (3) *salivary* digestion, (4) *deglutition*, (5) *gastric digestion* and (6) *intestinal digestion.* Prehension, mastication and deglutition cannot properly be looked upon as digestive processes, inasmuch as they involve no chemical change. They are, however, necessary occurrences, and cannot be disregarded. Of course, absorption and "internal digestion" are supposed to follow gastro-intestinal or "external digestion," and assimilation or cell appropriation to follow absorption.

Prehension.

Prehension is simply the taking of food into the mouth. Its mechanism in the human adult is so familiar that it needs no description. In the sucking child it is more complex. The buccal cavity is closed posteriorly by the application of the velum

palati to the base of the tongue. The tip of the tongue is applied to the hard palate, and successive portions of it (going backward) being applied in the same way leave a vacuum in front, and liquids are drawn into the mouth. The mechanism of drinking is the same.

Mastication.

Object.—The object of **mastication** is to grind up the food that it may be swallowed, and that the various digestive fluids, particularly the saliva and gastric juice, may have more ready access to its parts. To pass to the stomach food which has been improperly triturated and softened by saliva it to tax that organ unnecessarily, and this is not infrequently an important etiological factor in dyspepsia.

Mechanism.—Mechanically, mastication is effected by the action of the lower jaw, aided by the tongue, lips and cheeks. This remark presumes of course that the teeth are intact. Lateral and antero-posterior movements of the inferior maxilla combine with its simple elevation to compress and grind the food between the teeth. The muscles which depress the lower jaw are the *digastric*, *mylohyoid*, *geniohyoid* and *platysma*. Those which elevate it are the *temporal*, *masseter*, *internal* and *external pterygoids*. The attachments of the external pterygoids are such that by their simultaneous action the maxilla can be thrown forward by their alternate contraction from side to side. The **tongue** is active during mastication in carrying the mass to this or that part of the buccal cavity that it may be completely comminuted. It also gives accurate information as to the size and stage of mastication, salivary action, etc., of the bolus in the mouth. The **cheeks,** as is shown in facial palsy, are quite important in keeping the food from between them and the teeth. The **lips** prevent the escape of liquids from the mouth, besides assisting in prehension.

Salivary Digestion.

The action of saliva and mastication go on together. For the histological structure of the salivary glands and general properties of saliva, together with the mechanism of secretion, see section on Secretion, page 37 *et seq.* We are concerned here with its digestive properties only.

Composition of Saliva.—Chemically, it consists per thousand of about 994 parts water and six parts solid—these solids being chiefly mucin, ptyalin, albumin and salts. The salts are mainly the chlorides of sodium and potassium, the sulphates of potassium, the phosphates of potassium, sodium, calcium and magnesium, and sulphocyanide of potassium. The mucin gives the ropy consistence to the fluid and serves a mechanical purpose only. The sulphocyanide of potassium is unusual in the body secretions and its presence here is interesting. It may represent an end product of proteid metabolism. The true digestive value of saliva is due to **ptyalin,** an amylolytic enzyme.

Function.—The function of this secretion is twofold, (*a*) mechanical and (*b*) chemical.

(*a*) From a **mechanical** standpoint (1) it facilitates phonation, mastication and gustation by maintaining a proper degree of moisture in the mouth; (2) its more watery parts (parotid) mix with the food, dissolving part of it, so that it may be more easily masticated and swallowed while its more viscid parts (submaxillary and sublingual) spread over the surface of the bolus to aid in deglutition.

(*b*) From a **chemical** standpoint, the function of the saliva is to *convert starch into sugar.* It does this through the agency of its enzyme, **ptyalin,** which conforms to the characteristics of enzymes already noted. Maltose ($C_{12}H_{22}O_{11}+H_2O$) is the form of sugar produced, but there are several intermediate substances formed before maltose finally results. The starch molecule ($C_6H_{10}O_5$) was formerly supposed to simply appropriate a

molecule of water to form dextrose (grape sugar, glucose, $C_6H_{12}O_6$), but it is now thought that there is a succession of hydrolytic changes with the production of dextrin and maltose. That is, the starch molecule appropriates a molecule of water; this new molecule splits into a certain kind of dextrin and maltose; the dextrin left itself appropriates water and splits up into another kind of dextrin and maltose; this last dextrin goes through a similar process with a like result, until finally only maltose is produced. Some dextrose may be produced. It will be seen under gastric digestion that mineral acidity will also convert starch into sugar, but in this case the form of sugar is dextrose.

The effect of temperature on the action of enzymes has been noticed. The optimum for ptyalin is 100° Fahrenheit. The reaction of saliva is alkaline and its effect on starch is stopped by an acid medium, since the enzyme is thereby destroyed. However, ptyalin has been shown to act even a little better in perfectly neutral than in alkaline solutions (Chittenden). The action of this substance on starch is very much facilitated if the starch be cooked; in fact, its action on uncooked starch is so slow as probably to be inconsequential in digestion. Cooked starch becomes hydrated, and furthermore has its cellulose capsule removed from the granulose, both of which circumstances make it much more susceptible to salivary influences.

However, it must be admitted that the practical effect of ptyalin in digestion is not very considerable, mainly because the food is not kept in the mouth long enough. Although large quantities of saliva are swallowed with the food, its action in the stomach is inhibited by the acidity of the gastric juice. The conversion of starch into sugar is continued and concluded in the small intestine. It therefore follows that the chief value of the saliva is in the *mechanical* function already referred to.

Deglutition.

The act of deglutition is commonly divided into three periods, depending upon the part through which the food is passing. During the first period the bolus passes from the mouth through the isthmus of the fauces, during the second through the pharynx, and during the third through the esophagus into the stomach. A brief reference to the anatomy of these parts is necessary.

Fauces.—The isthmus of the fauces is the opening at the back of the mouth, bounded below by the base of the tongue, above by the soft palate and uvula, and laterally by the pillars of the fauces, between which are the tonsils. The **anterior pillars** are easily seen when the mouth is opened widely, and consist of the palatoglossi muscles with their covering mucous membrane. The **posterior pillars** approach each other more nearly than the anterior, and consist of the palatopharyngei muscles and their covering mucous membrane.

Pharynx.—The pharynx extends from the basilar process of the occipital bone above about four and a half inches downward. It communicates with the posterior nares, the mouth, the Eustachian tubes, the larynx and esophagus. The tube is made up of two coats, an external muscular and an internal mucous. The **muscular** coat consists of the three constrictors and the stylopharyngeus. The **mucous** coat is covered in its upper part with columnar ciliated and in its lower part by pavement epithelium.

Esophagus.—The esophagus runs a course of about nine inches from the end of the pharynx, at a point behind the cricoid cartilage, to the stomach, which it enters a little to the left of the median line. The coats of the esophagus are two, an external muscular and an internal mucous. The **external** coat has its fibers disposed in two layers, longitudinal and circular. The circular layer is internal. In the upper third of the esophagus the fibers of the muscular coat are all striped, but at

the beginning of the middle third they begin to give place to plain fibers, and these latter progressively increase, to constitute virtually the whole muscular coat at the diaphragm. The **internal** mucous coat is lined by squamous epithelium, and, except during the passage of substances through the esophagus, is thrown into longitudinal folds. The outside fibrous tissue which attaches the whole esophagus to the surrounding tissue need not be considered as a proper coat of that organ.

Mechanism of Deglutition.—The **first period** of deglutition is voluntary but automatic, like respiration. The morsel of food is forced toward and through the fauces by the tongue, which presses from before backward against the hard palate, with the bolus above it. That the tongue is mainly concerned in this act is shown by inability to swallow when this organ is absent, unless the food be pushed far back into the mouth by the finger or other means.

The mechanism of the **second period** is much more complex. The food must pass through the pharynx into the esophagus, and must not be allowed to enter any of the other openings communicating with the pharynx. The larynx especially is to be protected. Since the air enters through the posterior nares *above* the isthmus and must enter the larynx *in front of* the esophagus, it follows that the current of air would cross the current of food if swallowing and respiration took place together. Consequently respiration is suspended during deglutition. As soon as the food has passed the fauces, the elevators of the hyoid raise that bone, and with it the larynx. It is at the same time pulled a little forward, and since the pharynx is attached to the larynx posteriorly, the former necessarily follows the movement of the latter, and is thut *slipped under* the base of the tongue and the entering bolus. With elevation of the larynx the superior constrictor of the pharynx contracts upon the food, and passes it quickly to the grasp of the middle constrictor, which in turn hands it to the inferior constrictor and thence to the esophagus.

The posterior nares are protected by contraction of the posterior pillars and the superior constrictor. The laryngeal opening is protected by the epiglottis. When the tongue is forced back and the larynx raised the natural effect would be to fold the epiglottis down over the laryngeal opening. At the same time contraction of the pharyngeal muscles draws together the sides of the larynx and aids in closing the glottis. Furthermore, the vocal cords fall together (as they always lie except during inspiration—and inspiration is now suspended).

The **third period** passes the food through the esophagus into the stomach by contraction from above downward of successive portions of its muscular wall. Contraction of the longitudinal fibers draws the mucous membrane above the bolus. Then the circular fibers, contracting in successive segments from above downward, force the bolus before them. These movements are continued until the food reaches the stomach. The time consumed in swallowing a given article is about six seconds.

This is the mechanism which carries all materials through the alimentary canal from the esophagus to the anus. It is called **peristalsis,** or **vermicular (worm-like) action.**

Nervous Control.—While nearly all the muscular tissue concerned in deglutition is of the striated variety, the whole process, except the first, which is automatic, must be considered as reflex. The mechanism of deglutition is one of the best examples of finely coördinated muscular action to be found. The *afferent fibers* concerned are from the 5th, 9th and 10th, and the superior laryngeal branch of the last. The *efferent fibers* are from the 5th, 7th, 9th, 10th, and 12th. The **center** for the reflex is supposed to be far forward in the medulla.

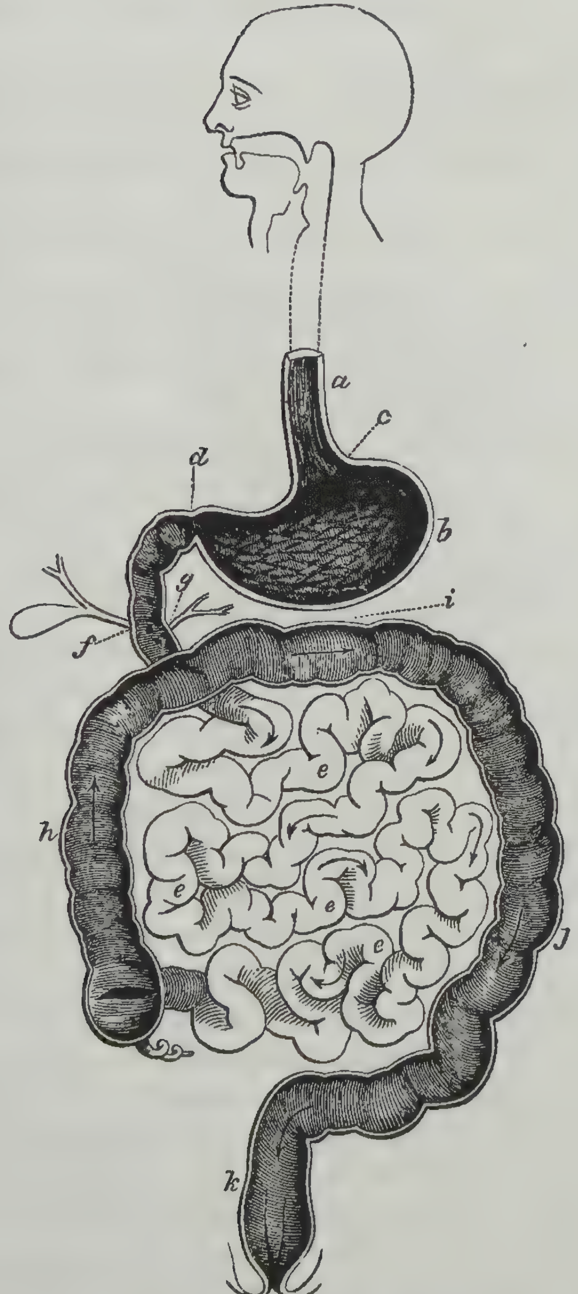
It ought to be added that the Kronecker-Meltzer theory of deglutition assails with considerable plausibility the mechanism of deglutition as above given. In a word, this theory holds that when the bolus of food rests upon the dorsum of the tongue, and the tip of that organ prevents, by its apposition to the hard

palate, the escape of the food forward, the *mylohyoids* contract with great force, compress the food, and it escapes by the route of least resistance, which is backward. It is thus *shot* into the esophagus, and the contraction of the pharyngeal muscles only supplements that of the mylohyoids.

Gastric Digestion.

Anatomy.—The stomach is situated beneath the diaphragm in the upper part of the abdominal cavity, and is moored by the esophagus and folds of the peritoneum. Its general shape has been compared to that of the bagpipe. Its large, or **fundic,** end is to the left; its small, or **pyloric,** to the right. By far the greater part of the organ is to the left of the median line. A very considerable portion is to the left of the esophageal opening. Except when distended, its anterior and posterior walls hang in an approximately vertical direction, and are usually in contact by their mucous surfaces. Its greatest length when moderately distended is about fourteen inches, its transverse diameter about five inches, and its capacity about five pints. At the point where the anterior and posterior walls meet inferiorly, the **great omentum** (the peritoneum from the two walls) is given off. This is the **greater curvature** and has the *gastro-epiploica-dextra* and the *gastro-epiploica-sinistra* arteries running along it between the two folds of the omentum. Where the anterior and posterior walls meet superiorly, the stomach is joined by the **lesser omentum,** the two layers of which are continued in front and behind as the serous covering of the stomach. This is the **lesser curvature,** and has the *gastric* and *pyloric branch* of the hepatic arteries running along it between the two layers of the lesser omentum. The large left hand portion of the stomach cavity is called the **fundus** or **greater pouch.** The opposite portion of the cavity is called the **lesser pouch** or **antrumpylori.** At one end is the **cardiac** or **esophageal opening,** at the other the **pyloric.**

FIG. 45.



Human alimentary canal.

a, esophagus; *b*, stomach; *c*, cardiac orifice; *d*, pylorus; *e*, small intestine; *f*, biliary duct; *g*, pancreatic duct; *h*, ascending colon; *i*, transverse colon; *j*. descending colon; *k*, rectum. (*Collins & Rockwell.*)

Histology.—The coats of the stomach walls are three. From without inward these are the (1) *peritoneal*, or *serous*, (2) *muscular* and (3) *mucous*.

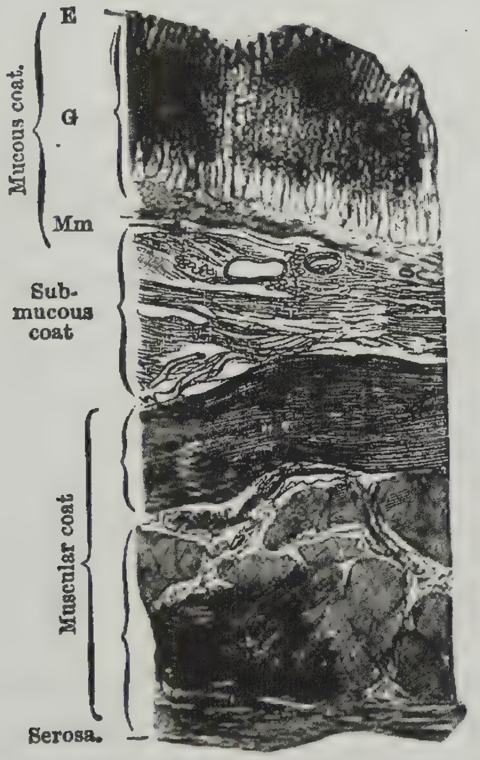
1. The **peritoneal** coat covers the whole of the organ excepting an inconsiderable linear area, where the two layers of the lesser (gastro-hepatic) omentum join it along the lesser curvature, and a similar area along the greater curvature, where the serous coats of the anterior and posterior walls leave the organ to form the great omentum. This coat is simply a fold given off from the peritoneum to envelop the stomach in practically the same manner as the other abdominal viscera. Its structure is that of serous membranes in general.

2. The **muscular** coat, varying in thickness from $\frac{1}{60}$ in. over the fundus to $\frac{1}{12}$ in. at the pylorus, is disposed in three layers, (*a*) external longitudinal, (*b*) middle circular and (*c*) internal oblique. The **longitudinal** fibers are continued from the corresponding fibers of the esophagus. They are marked along the lesser curvature, but not very distinct over other parts. The **circular** fibers are not abundant to the left of the esophageal opening. They progressively increase toward the right, and at the pyloric opening constitute a distinct and powerful muscular ring, the *pyloric sphincter*, which, projecting into the lumen presents a more or less flat surface on the duodenal side to prevent the regurgitation of food. The **oblique** fibers are supposed to be continuous with the circular fibers of the esophagus. They extend over the greater pouch from a point just to the left of the esophageal opening to a point on the greater curvature, about the junction of the middle and pyloric thirds. Here, at the right hand limit of the oblique fibers, the stomach is said during digestion to be considerably constricted, so that a temporary sphincter is established. This point is the point of separation between the fundus and the antrum pylori, and is sometimes called the *sphincter antri pylorici*. The fibers of the muscular coat are of the plain variety, as is all the gastro-intestinal muscular

tissue from the lower end of the esophagus to the external sphincter.

3. The **mucous** coat has an average thickness of about $\frac{1}{25}$ in., is loosely attached to the muscular coat, and, except during gastric digestion, is thrown into longitudinal rugæ. It con-

Fig. 46.



V. S. Wall of human stomach.
E, epithelium; *G*, glands; *Mm*, muscularis mucosæ. × 15. (*Stirling*.)

sists of columnar epithelium resting upon a basement membrane, beyond (underneath) which is the capillary blood supply. Throughout the greater part of the stomach the mucous membrane can be shown to be divided by delicate connective tissue into numerous polygonal depressions, from the bottom of which extend the gastric glands. For a description of these glands

and the general properties of the gastric juice, together with the mechanism of gastric secretion, see Secretion, page 42 *et seq.*.

Condition of Food on Entering Stomach.—The food has entered the stomach in the same condition in which it left the mouth. It has been more or less completely triturated by mastication; the whole has been moistened, and a part dissolved by the saliva. All the materials taken in have been thoroughly mixed with each other, and some of the starch has been converted into sugar. The reaction is now alkaline, unless the acidity of the articles taken has been too great to be overcome by the alkalinity of the saliva—in which case there would be no amylolytic change. Excepting *starch*, all foods entering the stomach are chemically unaffected. It remains to see what happens to the foods under the influence of gastric digestion. These changes are brought about by the gastric juice aided by muscular movements of the stomach.

Gastric Juice.—Gastric juice may be secured in several ways, but the most reliable article for experimentation is taken from a previously established gastric fistula in one of the lower animals. It is a thin, almost colorless liquid of an acid reaction, and a specific gravity of 1005 to 1009. Chemically it contains per thousand about 973 parts water and 27 solids. Proteid substances compose some 17 of the 27 parts of solid matter. These substances are mainly mucin, **pepsin** and **rennin.** The most important non-nitrogenous constituent is free **hydrochloric acid.** The others are chiefly the chlorides of sodium, potassium, calcium, and ammonium, and the phosphates of iron, calcium, and magnesium. Gastric juice will resist putrefaction for a long time, probably on account of the free acid. Its digestive properties are due to the proteolytic enzyme, pepsin, the milk-curdling enzyme rennin, and the free hydrochloric acid.

Hydrochloric Acid.—The amount of free hydrochloric acid present in normal gastric juice is from two-tenths to three-tenths

of one per cent. It has been frequently claimed that the acidity of this secretion is due to lactic acid, but while it cannot be denied that lactic acid, from the fermentation of carbonydrates is, or may be, normally in the stomach during digestion, yet hydrochloric acid is undoubtedly the free acid proper to the gastric juice. Digestion, however, will proceed under a proper (variable) degree of an acidity from almost any acid.

Theories as to the method of production in the stomach of hydrochloric acid are noticed under Secretion. It is very probably a product of the parietal cells in the so-called acid or fundic glands, but beyond the fact that it is manufactured from the neutral chlorides of the blood in the mucous membrane, nothing is definitely known. Beyond an insignificant effect in converting cane sugar into dextrose, its function is a passive one, namely, that of simply making the secretion acid, so that pepsin may act upon the proteids.

Pepsin.—Pepsin is a proteolytic enzyme, the composition of which has not been determined. From the definition, it converts proteids into peptones. It operates only in an acid medium. Hence its action is contingent upon the presence of another constituent of the gastric juice, namely, *hydrochloric acid.* Pepsin is a typical enzyme, and reference to the characteristics of those bodies will avoid repetition of its properties here.

Rennin.—Rennin has the property of *coagulating milk.* It acts upon the soluble proteid of milk (casein), changing it into an insoluble product, which is precipitated. Acids also will coagulate casein. Milk standing has lactic acid produced by the action of bacteria upon the lactose in it, and this acid precepitates the curd. The acid of the gastric juice might be sufficient to bring about this result, but the quick coagulation of milk when it is introduced into the stomach is probably not due to the acid, since neutral extracts of the gastric mucous membrane will themselves curdle milk. After coagulation the action of pepsin begins and the casein is converted into peptones in the

usual manner. The value of the curdling process is not apparent.

Action of Gastric Juice on Foods. (*A*) *On Proteids.*—A familiar test for the proper performance of gastric digestion is the observation of the effect of the juice in a given case upon the white of an egg (proteid). In normal gastric juice, or in a properly prepared artificial solution, the egg is seen to swell up and dissolve. This soluble proteid is now called **peptone,** and it differs from the proteid of the egg in certain important respects, to be noted later. But, although peptone is the final product of pepsin-hydrochloric action, there are certain substances produced intermediate between the initial proteid and the final peptone, just as in case of the formation of maltose by ptyalin. Some of these substances have been called acid-albumin, parapeptone, propeptone, etc. But whatever they may be, the nomenclature of Kuhne is being largely followed at present. He supposes that the first product is an acid albumin which he calls **syntonin**; that syntonin under the influence of pepsin undergoes hydrolysis, taking up water and splitting into **primary proteóses**; that each of these primary proteoses takes up water and splits into **secondary proteoses**; that these last undergo a similar change with the production of **peptones**; so that the successive substances are *proteid*, *syntonin* (acid-albumin), *primary proteoses*, *secondary proteoses*, *peptones.*

Peptones can be shown to be different from syntonin and the proteoses by chemical reaction. The chief object of proteolytic digestion is to get the proteids into a diffusible condition. Peptones differ from proteids in at least three important respects: (1) They can *pass through animal membranes*, that is, *can be absorbed;* (2) they are *no longer coagulable by heat or many acids;* (3) they are *capable of assimilation* by the cells after they have been absorbed.

(*B*) *On Carbohydrates.*—There is no enzyme furnished by the stomach to affect any of the carbohydrates. It is true that

salivary digestion proceeds in some small degree in the stomach. Saliva is swallowed with the food, and until the reaction becomes acid (which cannot be immediately), there is no reason why the conversion of starch into maltose should not proceed. It is also true that the mere acid of the gastric juice can slowly convert cane sugar into dextrose. Simple acidulated water will do the same.

(*C*) *On Fats.*—Neither is there any fat-splitting enzyme in the gastric secretion. So far as any chemical change is concerned the fats leave the pylorus in exactly the same condition as they entered the mouth. Their physical condition, however, undergoes some change in the stomach. The body temperature is sufficient to liquefy them, the vesicles in which the droplets are contained are dissolved, and thus set free, they become a part of the mechanical mixture, chyme, and are made easier subjects of intestinal digestion.

(*D*) *On Albuminoids.*—The albuminoids are acted upon by pepsin and hydrochloric acid in much the same way as are the proteids. Taking gelatin as a type, gelatoses are formed instead of proteoses. It is stated that peptic digestion does not go further than the gelatose stage with the albuminoids, conversion into peptones taking place under the influence of trypsin.

Resistance of Stomach Wall to Digestion.—It would be interesting to know why the stomach (or the intestine) does not digest itself. If a portion of the stomach of another animal be placed in that of a living animal, it will be digested; or if the circulation be cut off from a limited area of the stomach, the secretion will frequently digest that part of the organ and bring about a perforation; or further, if any living part of an animal, as the leg of a frog, be fastened in the stomach of another animal, it will likewise be digested. The last instance would seem to lead to the conclusion that living matter can be digested, but in reality it is shown (Bernard) that the tissue is first *killed* by the acid, and that no digestion takes place in the alkaline intestinal

juice. But why the stomach is not thus attacked when other living tissue is remains obscure. The most plausible theory is that the gastric epithelium is possessed of some power, mechanical or physical, the nature of which is unknown, inhibiting the action of the gastric juice, most probably by *preventing its absorption.*

"A nearer approach to an explanation seems to have been attained in the discovery of an antipeptic and antitryptic action of the stomach and intestinal mucosa. This action is probably due to antienzymes which are found throughout the whole animal scale and occur not only in the intestinal tract, but also in cells of other organs." (Tigerstadt.)

Movements of the Stomach.—Whether the exact details of the muscular movements of the stomach be known or not, the essential fact to be remembered is that the organ is in a more or less continuous state of muscular activity for several hours after the ingestion of an ordinary meal, and that this activity results in the physical disintegration of most of the solids introduced, in the thorough mixing of all the classes of foods with each other and with the gastric juice, and in the passage from time to time of such parts as have been reduced to a pultaceous condition through the pylorus into the duodenum, until finally the stomach is empty.

In considering the mechanism of these movements a division of the organ into two segments, fundic and pyloric, by the *sphincter antri pylorici* is to be kept in mind. When food has entered the stomach the peristaltic wave of contraction begins at the splenic end and passes toward the right. This contraction is comparatively weak, is mainly evident along the greater curvature, and increases in strength as it passes towards the pylorus. Its wave-like character is due to the contraction and subsequent relaxation of successive bands of circular and oblique fibers. Regurgitation of food is prevented by a rhythmical contraction of the lower end of the esophagus, and the effect

of this muscular wave (peristalsis) in the fundus is to force the food towards the pylorus. But when the right end is reached, the rather firm contraction of the sphincter antri pylorici prevents the entrance into the antrum of all except the liquid or semi-liquid parts. The food, thus denied admission to the antrum, takes a course along the lesser curvature to the splenic end, then back along the greater curvature, and such parts of it as have, during this revolution, been sufficiently dissolved pass into the antrum. These revolutions continue until the fundus has been emptied.

It is not to be supposed that food has been accumulating meantime in the antrum. Indeed, it is certain that muscular contractions are here much more active than in the fundus, where the movements are slow and of a rather compressing nature. It is thought that very soon after the entrance of food from the fundus the entire muscular wall of the antrum undergoes very strong contraction of a peristaltic (possibly systolic) nature, and the pultaceous parts of its contents are sent with some force into the duodenum. Those which are not sufficiently dissolved to pass the pyloric sphincter are said to excite an anti-peristaltic movement, whereby they are thrown back into the fundus for further digestion—the sphincter antri pylorici having now relaxed. However, substances which the gastric juice and contractions cannot dissolve will finally pass the pylorus, but they are probably delayed for a considerable time.

This succession of movements is continued with a rapidity and regularity varying with the condition of the organ and the nature of its contents. They last until the organ is emptied in part by the absorption of its contents, but mainly by their passage into the small intestine. Each circuit in the fundus probably occupies about three minutes, and gastric digestion as a whole lasts usually from two to five hours. The contraction and relaxation of plain muscle is much slower than that of striped.

It is the fundus, and not the pylorus, which serves as a reservoir

and in which the greater part of gastric digestion occurs. The precise condition of the pyloric sphincter during gastric digestion is unknown. It may have simply an exalted degree of tonicity which does not completely close the opening and which can be overcome by pressure, or it may be tightly contracted and require a distinct nervous dispensation to effect its relaxation for the passage of fluids as well as solids. It would seem that the length of time for which food is detained in the stomach depends more upon its *physical* condition than upon its chemical—that is, than upon uny stage of *digestion* which it may have reached; for it can be shown that fluids pass very quickly into the intestine.

The secretory occurrences during these movements are of the greatest importance (see p. 42).

Nerve Supply.—The stomach is supplied with pneumogastric and sympathetic fibers. These latter can be traced through the solar plexus, splanchnics and cervical ganglia to the spinal cord. They exert an inhibitory effect on the muscular tissues; their stimulation causes *relaxation.* The vagus fibers are motor; their stimulation causes *contraction.* But these nerves serve only to *regulate* the muscular movements. It is the stimulus of food in the stomach which excites gastric peristalsis. It is not stopped by section of these nerves, though it may be interfered with. This stimulation is exerted either directly upon the nerve fibers or upon the ganglia of the stomach wall.

The conditions influencing gastric digestion operate mainly through changes in the quality and quantity of gastric juice. For mention of some of these, together with the nerves controlling gastric secretion, see article on Secretion.

Intestinal Digestion.

Anatomy.—The small intestine extends from the pylorus to the caput coli, and is about twenty feet in length. It lies in numerous coils which are held loosely in place by a fold of peritoneum running from one side of the great abdominal vessels, envelop-

ing the gut, and returning to the parietal wall on the opposite side of the vessels. The fold thus attaching the intestine to the abdominal wall is the **mesentery.** The distance along the mesentery from this parietal region to the gut is three or four inches, except at the beginning and end of the small intestine, where it is shorter, to bind the tube more firmly in place. The upper eight or ten inches of the small gut is called the **duodenum,** the next eight feet the **jejunum,** and the remainder the **ileum.** No anatomical peculiarity separates these parts. Their average diameter is about one and a quarter inches.

Histology.—The wall of the intestine is in three layers, external or serous, middle or muscular and internal or mucous.

The **external** layer consists of the enveloping fold of peritoneum and needs no description, except that, like serous membranes elsewhere, it furnishes a lubricating secretion to provide for the easy gliding of the intestines over each other and over the other viscera. The **middle** coat has its muscular fibers disposed in two layers, an external longitudinal and an internal circular. The latter is the stronger. Between the two muscular layers is the nervous *plexus of Auerbach;* between the circular layer and the mucous coat is that of *Meissner.* These communicate with other by fibers of extension. The **internal** mucous coat presents several points deserving mention. These are (1) valvulæ conniventes; (2) villi; (3) secreting glands, (*a*) of Brunner and (*b*) of Lieberkuhn; (4) solitary and agminate glands.

1. The **valvulæ conniventes** are simply transverse folds or tucks of the entire mucous membrane, each of which extends from one-third to one-half around the circumference of the tube and projects by its middle portion sometimes to the center of the lumen. These small folds, 800 to 1000 in number, extend from about the middle of the duodenum to the beginning of the last third of the ileum and greatly increase the length of the mucous membrane over that of the gut proper. They are not effaced

by the passage of food or by other circumstances, for the two surfaces of the fold which are in apposition are bound together by loose connective tissue. The fold as a whole, however, is freely movable upward or downward in the intestine and has no tendency to obstruct the canal. The only function of the valvulæ conniventes is to furnish a greater secreting surface and,

FIG. 47.

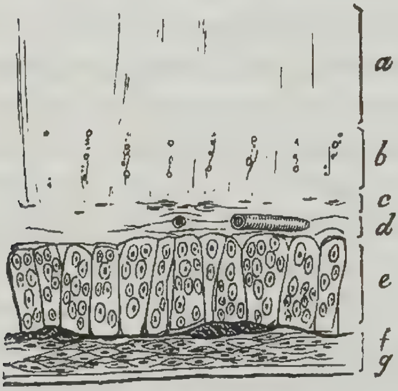


Diagram of a longitudinal section of the wall of the small intestine.

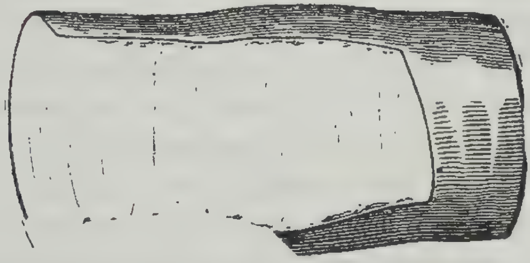
a, villi; *b*, Lieberkuhn's glands; *c*, tunica muscularis mucosæ, below which lies Meissner's nerve plexus; *d*, connective tissue in which many blood and lymph vessels lie; *e*, circular muscle fibers cut across with Auerbach's nerve plexus, below it; *f*, longitudinal muscle fibers; *g*, serous coat. (*Yeo.*)

by somewhat retarding the passage of the alimentary mass, to subject it for a longer time to the digestive fluids.

2. The villi are especially important in connection with absorption, and their description properly belongs under that head. They are conical elevations responsible for the velvety character of the mucous membrane. They exist in great numbers from the pylorus to the ileo-cecal valve, covering the valvulæ conniventes as well as the general surface of the mucous membrane. The largest are about $\frac{1}{20}$ in. long and $\frac{1}{70}$ in. in diameter at their base. They are only elevations of the mucous membrane containing a central tube, the *lacteal*, which is nothing but an intestinal lymphatic. The structure from without inward—that is,

from the surface of the villus inward to its center—is (1) a layer of columnar epithelium resting upon a delicate basement membrane; (2) lymphoid tissue containing abundant capillaries and

FIG. 48.

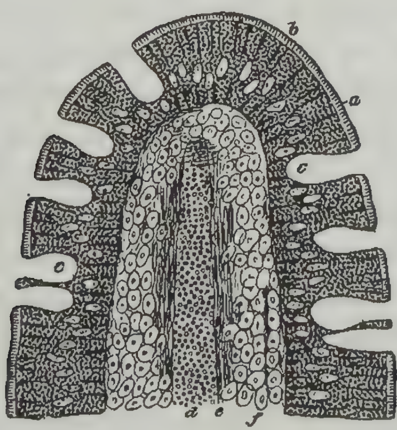


Portion of the wall of the small intestines laid open to show the valvulæ conniventes. (From *Yeo* after *Brinton.*)

connective tissue cells; (3) a thin layer of plain muscle fibers continuous from the intestinal wall; (4) the lacteal, whose endothelial wall contains many stomata.

3. The **glands of Brunner** and the **crypts of Lieberkuhn,** or intestinal tubules, are supposed to produce the succus entericus.

FIG. 49.



Vertical section of a villus of the small intestines of a cat.

a, striated border of the epithelium; *b*, columnar epithelium; *c*, goblet cells; *d*, central lymph-vessel; *e*, smooth muscular fibers; *f*, adenoid stroma of the villus in which lymph corpuscles lie. (*Kirkes* after *Klein.*)

The former are chiefly limited to the upper half of the duodenum. The latter exist throughout the small and large intestine. For further description of them see Secretion, page 47.

4. The **solitary** and **agminate** glands are not supposed to contribute to the production of the intestinal juice. They are alike in structure, the agminate glands being only a collection of solitary glands. The former are the **Peyer's patches,** so important in the pathology of typhoid fever. These patches are usually about twenty in number and confined to the lower two-thirds of the ileum, where they occupy that portion of the circumference of the tube opposite the attachment of the mesentery. Their average dimensions are $1 \times 1\frac{1}{2}$ in. They consist essentially of lymphoid tissue, the separate follicles of which are surrounded by lymphatics and penetrated by blood-vessels. They are covered by villi, but the valvulæ conniventes cease at their edges. The solitary glands are more widely distributed than the agminate.

The **chyme,** having passed from the stomach to the small intestine, encounters three digestive fluids, pancreatic juice, bile and intestinal juice. These are, of course, mixed together, but none interferes with the action of the other.

PANCREATIC DIGESTION.—For a description of the pancreas and the mechanism of its secretion see page 48.

The pancreatic juice has an alkaline reaction, and a specific gravity of about 1040. It quickly undergoes putrefaction, and coagulates if heated. Taken from a recent fistula, it contains of water about 900 parts per 1000 and about 100 parts solids. Organic substances constitute the main part of the solids.

The enzymes, trypsin, amylopsin, and steapsin constitute the main part of the solids. The salts are the phosphates of sodium, calcium and magnesium, the chloride and carbonate of sodium.

Trypsin.—Trypsin, like pepsin, converts proteids into peptones. Nothing positive is known of its composition, but it is possessed of the usual characteristics of enzymes regarding tem-

perature, etc. It differs from pepsin in that its proteolytic action is more powerful and can take place in alkaline media. It will also act in neutral or weakly acid media. The opinion is advanced that while the gastric juice is capable of converting proteids into peptones, as a matter of fact it does not usually carry the process further than the proteose stage, and thus prepares the proteoses for tryptic digestion.

It was seen that the successive products of pepsin-hydrochloric digestion are syntonin, primary proteoses, secondary proteoses and peptones. In tryptic digestion it seems that, in the splitting process, the syntonin (here alkali-albumin) and primary proteose stages are omitted, and the first product is *secondary proteoses*, which are split into peptones. Furthermore, trypsin goes a step beyond with some of the peptones and converts them into simpler compounds, the best known of which are leucin and tyrosin. These are found normally in the intestinal canal, but the physiological importance of this conversion is not apparent. The opinion that it is a useless sacrifice of useful peptones does not seem warranted.

Amylopsin.—The amylolytic enzyme, amylopsin, is identical in its action with ptyalin. For the supposed reactions taking place see page 144. This enzyme is very important, for it has been remarked that the action of ptyalin is probably rather inconsequential, and by far the greater portion of the starch, which constitutes a large part of our ordinary food, must be digested in the small intestine—and almost entirely by amylopsin.

Steapsin.—Under the influence of steapsin neutral fats take up water and undergo hydrolysis, with the production of glycerine and the fatty acid corresponding to the kind of fat which is split up. In the intestine it is probable that only a part of the neutral fats are thus split in glycerine and fatty acids. The fatty acids thus formed unite with the alkaline salts to form soaps, and these soaps, aided by intestinal peristalsis, convert the remaining fats into an emulsion. The products of fat diges-

tion are therefore *glycerine*, *soaps*, and *emulsions*, all of which can be absorbed in a way to be noted later. While the emulsification of fats under the influence of soaps (fatty acids and alkaline salts) is an undoubted effect, the method of procedure is unknown. It is certain that the emulsification is aided by the presence of bile, although this fluid possesses no fat-splitting enzyme.

Bile of Digestion.—The bile is not, properly speaking, a digestive fluid, for it contains no enzyme capable of effecting digestive changes in any of the foods; but it so materially affects the action of some of the other fluids that it cannot be overlooked in a discussion of intestinal digestion. The liver, its anatomy, functions, etc., are best considered elsewhere (see page 51, *et seq.*), and reference will here be made only to the connection of the bile with digestion.

So far as the bile acids, glycocholic and taurocholic (combined to form salts of sodium) are concerned, the fluid is a secretion, and it is these which are mainly concerned in the digestive process. The production of bile is continuous, but the gall bladder acts as a reservoir in which a part at least of the secretion is stored in the intervals of digestion, to be discharged in greater abundance when chyme enters the duodenum. While the action of bile in most of the digestive functions to be mentioned is obscure, it is known to have at least these uses:

1. It promotes intestinal peristalsis.

2. It has an inhibitory effect on putrefaction in the intestinal tract. By this it is not to be understood that the bile is directly antiseptic, for it undergoes putrefaction very readily itself, but only that in some way its withdrawal from the substances passing through the alimentary canal allows their more ready disintegration.

3. It aids in the emulsification of fats.

4. It promotes the absorption of fats. Recently the statement that the bile promotes all kinds of absorption has appar-

ently been successfully disproved, but it seems certain that "the bile acids enable the bile to hold in solution a considerable quantity of fatty acids, and possibly this fact explains its connection with fat absorption." (American Text-Book.)

THE SUCCUS ENTERICUS.—The intestinal secretion, or **succus entericus,** is a product of the crypts of Lieberkuhn and Brunner's glands. It is scanty, of a yellow color and an alkaline reaction. Opinions vary as to what foods are affected by this fluid, but since the more recent experiments have overcome some difficulties in obtaining specimens, the conclusions based upon them seem most reliable. It is said to have no effect on proteids or fats. It contains an **amylolytic enzyme,** which aids the pancreatic juice in converting starch into maltose. It also has an enzyme, **invertase,** which converts cane sugar into dextrose and levulose, as well as an allied enzyme, **maltase,** which converts maltose into dextrose. The carbohydrates are *absorbed* as dextrose, with the probable exception of lactose. It is mainly cane sugar, maltose (from starch) and lactose that are in the alimentary tract and require to be thus changed to dextrose.

It is not out of place to say that ptyalin produces maltose and a little dextrose, and that the pancreatic juice and succus entericus produce maltose and considerable dextrose. The maltose is converted into dextrose during the process of *absorption.* It is, therefore, customary to say that the carbohydrates are absorbed only as *dextrose.*

Movements of the Small Intestine.—The effect of intestinal movements is to force the contents onward through the ileocecal valve. Here it is that typical peristalsis is found. The main factor in the passage is the layer of circular fibers. Contraction of these fibers in the upper duodenum may at least be conceived to begin upon the introduction of chyme. The contraction passes down the gut in a wave-like manner, the wave being produced by the contraction of segment after segment of the circular fibers with relaxation just behind the ad-

vancing contraction. The tendency of such a movement is to force the alimentary mass along the canal. The longitudinal fibers are probably chiefly concerned in changing the position of the intestine and in shortening the tube, and thus slipping the mucous membrane above the bolus, so that it can be grasped by the circular fibers. A continuation and repetition of these movements, which are slow, gentle and gradual in character, is finally effectual in passing the contents into the colon. It is not probable that anti-peristaltic movements take place normally.

Nerve Supply.—Very probably the intestinal movements are naturally excited by the *food* and by the *bile.* It is probable also that these stimuli exert their influence through the ganglia of the plexuses of Auerbach and Meissner. The intestine receives fibers from the right vagus and the sympathetic. The former are probably motor (contractors) and the latter inhibitory (dilators). Here, as in the stomach, they are probably only *regulators* of the movements, without being actually necessary to peristalsis.

Large Intestine.

Anatomy.—The large intestine, known as the **colon,** is about five feet in length and is divided into **ascending, transverse** and **descending** portions. (See Fig. 45.) The **sigmoid flexure** is the terminal extremity of the descending colon and empties into the **rectum.** The small intestine communicates with the colon at right angles a little above the beginning of the latter, leaving below the opening a blind pouch, the **cecum,** or **caput coli.** From the posterior and inner aspect of the cecum runs off the **appendix vermiformis.** The diameter of the colon gradually decreases from two and a half to three and a half inches in the cecum to the beginning of the rectum. The ascending colon passes upward from its beginning in the right iliac fossa to the under surface of the liver, where it bends upon itself almost at a right angle (hepatic flexure). The transverse colon runs

directly across the upper part of the abdominal cavity to the lower border of the spleen, where an abrupt turn downward (splenic flexure) begins the descending colon. The lower part of the descending colon occupies the left iliac fossa in the shape of the letter S, and is the sigmoid flexure.

The **rectum,** which receives the contents of the sigmoid, is not straight, as its name indicates. It curves (1) to the right to reach the median line, (2) forward to follow the contour of the sacrum, and (3) backward in the last inch of its course. It has the shape of a dilated pouch, its lower termination at the anus being guarded by the powerful external sphincter of striated muscle. Its diameter is greatest below.

The **vermiform appendix** has the three coats common to the intestine, but its muscular coat is ill-developed. The peritoneal coat generally forms a short meso-appendix at the root of the organ. The blood supply of the organ is not abundant. It is greater in the female than in the male, a part of it coming through the appendiculo-ovarian ligament. The appendix has no function.

The **ileo-cecal valve,** guarding the opening between the large and small intestines, is made of two folds, upper and lower, of the muscular and mucous coats, which folds project into the large intestine. The serous coat runs directly over from the small to the large intestine at their point of junction, without being folded inward upon itself, as are the others. This prevents obliteration of the folds by distention. By this arrangement the two portions of the gut communicate only by a buttonhole slit, which is easily opened by pressure from the direction of the ileum but which pressure from the cecum tends to close more firmly. (See Fig. 45.)

Structure.—The large intestine has the usual three coats. The **peritoneal,** however, is lacking on the posterior part of the cecum, ascending and descending colons, these parts being bound down closely and having no meso-colon. The sigmoid

is entirely covered as is the upper third of the rectum. The middle third of the rectum has no serous coat behind, being firmly held in place, while the lower third lacks this coat entirely. The **muscular** coat is peculiar, in that its longitudinal fibers are collected into three quite strong bands, evident to the eye. When the rectum is reached they spread out over the whole circumference of that part of the canal. These bands are shorter, as it were, than the wall proper, and the consequence is that the whole length of the large intestine is gathered up into a number of pouches. The **mucous** coat is paler than that of the small intestine, presents no villi and is rather closely adherent to the subjacent parts. In it are found glands corresponding in appearance to the crypts of Lieberkuhn, and they are so classed; but they probably secrete mucous only. Some solitary lymphoid follicles also usually exist here.

Changes Taking Place in the Alimentary Mass in the Large Intestine.—Most of the substances which enter the large intestine have resisted the action of the various digestive fluids and are on their way to be discharged in defecation. Doubtless, though, some materials undergo digestive changes in the colon, not under the influence of any secretion there formed, but of the intestinal juice with which they are incorporated on leaving the ileum. The secretion of the mucous membrane of the large intestine furnishes no digestive enzyme, and the changes going on in the alimentary mass (now feces) are chiefly due to absorption. By some unknown process, however, rectal aliments of an easily digestible nature are absorbed, and that in a nutritive form. The *consistence* of the fecal matter increases in its passage through the colon, owing to the absorption of its more fluid portions. The bile pigment is responsible for the characteristic *color*. The *odor* is mainly due to bacterial decomposition, but partly to the secretion of the mucous membrane.

Bacteria in Intestinal Digestion.—The entrance of the bile and pancreatic juice into the duodenum changes to alkaline

the previously acid reaction of the chyme. But it is found that, when an ordinary mixed diet is given, the mass leaving the ileo-cecal valve has an *acid* (proteid) reaction, and that the proteids have not undergone putrefaction. The alkaline medium of the upper intestine favors bacterial activity, and it would seem that proteid putrefaction would ensue. But it is supposed that in health these bacteria set up fermentative changes in the carbohydrates, with the production of acids which inhibit proteid putrefaction, and account for the acid reaction at the ileo-cecal valve. When the mass has entered the colon the acidity is soon overcome and putrefaction is the usual consequence. It can be seen how readily this delicately adjusted balance may be disturbed by errors in the proper kind and proportion of food, etc. Some of the products of bacterial activity upon carbohydrates and proteids are leucin, tyrosin, indol, skatol, phenol, lactic and butyric acid. The object of the production of these substances is unknown.

Composition of Feces.—It seems at present that the main bulk of fecal matter is made up of substances which are contained in the intestinal secretions, and the alimentary canal is more important in excretion than was formerly supposed. These substances are waste matters from tissue metabolism. Besides these materials, the feces normally contain indigestible and undigested matters, inactive salts, stercorin, mucus, epithelium from the intestinal wall, coloring matter and substances resulting from bacterial activity. *Stercorin* is the converted form of cholesterin, a constituent of the bile. The coloring matter is from the pigment (*bilirubin*) of the same fluid. Of the bacterial products the most important are *indol* and *skatol*. They represent proteid putrefaction; they are responsible for the fecal odor; hence the characteristic difference in the odor of the contents of the ileum and colon. The reaction of fecal matter varies. The amount for the average person is about four and a half ounces per day.

Gases.—*Hydrogen, nitrogen* and *carbon dioxide* are found

normally in the small intestines. They serve to keep the tube patulous, and avoid obstruction, and also to prevent concussion. In the large intestine bacterial activity increases the number of gases present. Here, in addition to those found in the small intestine, there are *carburetted* and *sulphuretted hydrogen*, with others at times.

Movements of the Large Intestine.—The muscular contractions of the colon forcing the feces onward are of the same general character as those of the small intestine, though less violent. The contents thus passed analward by peristalsis accumulate gradually in the sigmoid flexure until defecation occurs.

Defecation.—The act of defecation is both voluntary and in voluntary;—voluntary in the relaxation of the external sphincter and involuntary in the peristalsis which brings the fecal matter to present at that muscle. It is probable that the rectal pouch does not usually contain feces, but that the desire to defecate is brought about by the entrance of the mass into it from the sigmoid. Then, if the desire be obeyed, peristalsis of the non-striated muscular coat continues, the internal sphincter of plain muscle relaxes, as does also the external of striped muscle, and evacuation takes place.

Usually, by an effort of the will, evacuation can be voluntarily prevented by maintaining the tonic contraction of the external sphincter. If the desire to defecate be disregarded, the fecal accumulation probably returns to the sigmoid, leaving the rectum comparatively empty. The act of evacuation is commonly aided further by voluntary contraction of the diaphragm and abdominal muscles. The lungs are filled, "the breath is held" (forcing down and holding the diaphragm), and the abdominal muscles likewise contract powerfully to compress the viscera and force the feces into the rectum. Pressure on the afferent nerves of the rectum probably sets up the desire to defecate, and the contraction of its walls, as well as the relaxation of the internal sphincter is a reflex act. The **center** is in the lower segment

of the cord, but it is connected with the cerebrum, as is shown by emotional influences on the act.

The average time occupied in the passage of the residue of an ordinary meal from the mouth to the rectum is about 24 hours. Something like 12 hours of this is thought to be spent in the large intestine.

While it has been endeavored to establish clearly the separate action of each fluid with which the aliment comes in contact, it is to be remembered that they form a mixture, the combined activity of whose component parts results in the extraction of all the nutritive material from the bolus in its long journey through the gastro-intestinal tract. It can hardly be said to be still at any time during that passage, the continual peristalsis to which it is subjected facilitating both the chemical action of the enzymes and the physical phenomenon of absorption.

(C) ABSORPTION.

Obviously digested materials are of no service in the vital economy until they are absorbed—first by the circulation and then by the tissues themselves. Here we will consider only their absorption from the alimentary canal, which process, in contradistinction to the other, may be termed *external absorption.*

While it is known that the laws of diffusion and osmosis outside the body are largely responsible for absorption within the organism there are many phenomena in connection with that process which cannot be explained under these laws, and which are indeed, in some cases, at variance with them. The only explanation at present to be offered of anomalous action is to refer it to some peculiar property inherent in the cells themselves—the epithelium in case of the alimentary canal. So profoundly important in connection with physiological activity are the laws of osmosis outside of the body, and what is known concerning the mutability of those laws inside the body, that a

brief consideration of the subject seems necessary to an intelligent conception of many vital phenomena.

Osmosis.—When two different kinds of gases are brought in contact they mingle with each other, making a homogeneous mixture. This is due to the continual motion of their molecules. When two different kinds of liquids are brought in contact, a homogeneous mixture results for the same reason—unless the liquids be non-miscible, as oil and water. If now the liquids happen to be separated by a membrane permeable by both, the result, while it may be delayed, will be the same. If, further, these liquids hold in solution substances the molecules of which can penetrate the interposed membrane, there will likewise be an interchange of these substances, and the fluids on both sides will come ultimately to have the same composition. This passage of liquids and dissolved matters through an animal membrane is known as **osmosis.**

It must be remembered that in the body particularly the interposed membrane may be permeable to the solvent, water, and less so, or not at all, to the dissolved substances. Materials which will in solution pass through a membrane are called *crystalloids;* those which will not, *colloids.* If simple water be on both sides of the membrane, the interchange continues because of incessant molecular motion; but the currents equalize each other, and no alteration in volume or composition becomes apparent. But if to the water on one side there be added a solution of some crystalloid, as sugar, the excess of water will pass to that side. The crystalloid in solution is said to exert an *osmotic pressure*, and that pressure depends upon the *density* of the solution. In course of time, however, the crystalloid passing itself through the membrane, conditions of equal volume and density will be established on the two sides of the membrane, and osmosis in either direction will cease to be apparent. But if the membrane be non-permeable to the dissolved substance, an excess of water will pass to the colloid side and will continue so to pass until finally it will be

inhibited by hydrostatic *pressure* on that side. This is taken as the measure of osmotic pressure for the colloid.

All substances in solution, whether crystalloids or colloids, exert a certain osmotic pressure; that is, they may be said to interfere with the passage of a current from their side of the membrane, and that interference depends on the number of molecules in solution, or, in other words, upon the density of the fluid. A fanciful but striking illustration refers the explanation to the continual molecular motion: the molecules of the dissolved substance act as a screen to protect the membrane from the water molecules, which are incessantly moving against it, and consequently, in a given time, more molecules of water will strike and pass through the membrane on the unscreened than upon the partially screened side. Evidently the number of molecules in solution (the density) has a material influence upon the escape of water from that side. Of course, since a crystalloid finally passes to the less dense side in sufficient quantity to establish an equilibrium, the effect of its osmotic pressure is only temporary; but while the osmotic pressure of a colloid may be less than that of a crystalloid, its effect is inclined to be permanent. For instance, if a hypertonic solution (one whose density is greater than that of blood serum) of sodium chloride be injected into the blood, the first effect is to cause an increased flow of water *to* the vessels, but soon enough sodium chloride passes out by osmosis to raise the density of the extravascular fluids, and thus to cause an escape of water *from* the vessels. On the other hand, the osmotic pressure exerted by the proteids of the blood is comparatively small. But since they are here chiefly as colloids and tend to maintain the concentration of the circulating fluid, their effect is a permanent factor influencing absorption into the blood-vessels.

Isotonic and *hypotonic* solutions are those having equal and less densities respectively as compared to blood serum. Hypotonic solutions are most easily absorbed; hypertonic least easily.

Application of these principles explains the rationale of giving some medicines in dilute and others in concentrated form. As to the direction of the current, the one of greater volume may be called the *endosmotic* and the one of lesser volume the *exosmotic*. For example, the current in ordinary absorption from the alimentary canal is usually termed endosmotic, though it may be reversed, as when magnesium sulphate is given.

When it is said that the greater current is from the less dense to the more dense fluid, no reference is had to the direction of the *solids* in solution. If there be only one solid concerned, it will be the one responsible for the difference in density and if it be a crystalloid, it will pass through the membrane until the density on the two sides is equal, and its direction will be opposite to that of the water. If on the side of less density there be another crystalloid in solution, but in less quantity than the solid on the side of greater density, it will pass in the direction of the greater current of water until conditions of equal concentration with respect to this solid are established. In the laboratory the final result in any case of dissolved crystalloid or crystalloids is two liquids absolutely identical in composition. A rectal enema, hypertonic with sodium chloride, will give up sodium chloride to the blood, but it may at the same time draw upon that fluid for urea, for example. This is suggestive when an attempt is made to explain the products of glandular secretion, excretion, etc. It may be that the capillary walls are permeable to certain substances in certain situations and not in others.

In the body it may be said that well-nigh all the vital functions are dependent upon osmosis. There are fluids separated by animal membranes everywhere. In the alimentary canal, for instance, is a fluid containing matters fit to be absorbed; ramifying in the wall of that canal are blood and lymph capillaries filled with fluid; while separating the two is an animal membrane consisting of the alimentary epithelium, a little connective tissue

and the endothelial lining of the capillaries. These are conditions most favorable for osmosis, but the osmotic laws of the laboratory are by no means immutable in the body.

From what has been said of osmosis in general, and considering variations due to conditions of circulation, etc., the following facts seem clear as to absorption in the body: (1) The substance must be in a liquid or gaseous state; (2) it must be diffusible; (3) the membrane must be permeable; (4) the greater current is toward the more dense solution; (5) the less dense the solution the more quickly will it be absorbed; (6) the greater the pressure in the vessels the less rapidly will absorption into them take place; (7) absorption is more rapid the more rapid the blood current (continually preventing "saturation" of the adjacent blood); (8) the higher the temperature the more rapid is absorption; (9) the "vital condition" of the cells is the most important factor of all.

A thorough grasp of these principles and probabilities will do much to clarify almost all the phenomena of vital activity, and many questions of a pathological nature.

Absorption from the Alimentary Canal.—It has been said that all digested materials must find their way into the blood. It is to be remembered that there are two ways by which they reach the vascular circulation; first, by direct absorption into the capillaries of this system, and second, indirectly, by absorption into the lymphatic circulation and passage thence to the left subclavian vein. Those lymph capillaries which are concerned in this absorption occupy the villi, and are called lacteals.

(*A*) *From the Stomach.*—Since all classes of food except fats have been partly digested in the stomach, it follows that all except fats may be absorbed here. However, as a matter of observation, the stomach is of much less importance in absorption than was once thought. Practically, it is found that water and salts are passed quickly on toward the duodenum and are not

largely absorbed in the stomach. Sugar and peptones are also found to be absorbed rather sparingly here. All these substances can undoubtedly be absorbed by the gastric mucous membrane, and their complete absorption is prevented only by their removal through the pylorus. It is interesting to note that alcohol and condiments, like pepper and mustard, greatly hasten absorption, either by increasing the blood flow or by directly stimulating the "vital activity" of the epithelium.

(*B*) *From the Small Intestine.*—Here absorption of all classes of food is possible, and here in fact most of the foods are absorbed. The digestive influences are more active upon all the aliments, the mucous membrane is well adapted to absorption by reason of its valvulæ conniventes and its villi, and the food necessarily remains in the small intestine for a considerable time. The fats are absorbed in the upper part of the small intestine; for they pass into the lacteals of the villi, and these do not exist in the lower ileum. The fluids swallowed are almost completely absorbed here, but their place is taken by the intestinal secretions. The proteids are absorbed to the extent of 85 per cent., more or less, before reaching the large intestine, and the carbohydrates almost entirely disappear.

(*C*) *From the Large Intestines.*—The absorption process in the large intestine is quite active. The passage of the mass through it is slower, and even occupies an absolutely greater time than the journey through the much longer small intestine. The consistence of the contents progressively increases owing to continual absorption of the fluid portions, until the pultaceous mass received by the cecum becomes almost solid in the sigmoid. The degree of consistence may be said to be greater the longer the sojourn in the large intestine. The proteids and carbohydrates which have escaped absorption in the small intestine are disposed of here, partly by bacterial decomposition, and do not appear as such in the feces. The absorption of easily digestible substances in solutions, such as eggs, etc., from the lower bowel,

although there is no digestive enzyme there, is a matter of common observation, but one which lacks explanation.

Forms in Which the Different Classes are Absorbed. 1. *Water and Salts.*—Of course, water is absorbed in connection with all the foods as a vehicle for them, but water and salts as such have been shown to be absorbed sparingly in the stomach. They are soon conveyed to the small intestine, where their rapid disappearance ensues. However, they may be absorbed anywhere in the alimentary canal. The loss of the water from the alimentary mass in the upper small intestine is compensated for by the secretions, so that the fluidity of the contents is not materially affected until the colon is reached. Here absorption of water is active, and the mass becomes more and more solid as the rectum is approached.

2. *Proteids.*—It is agreed that the first object of proteid digestion is to render the nitrogenous foods more diffusible. It is also agreed that the end products of such digestion, so far as alimentary absorption is concerned, are proteoses and peptones; and the natural conclusion, supported by experimental evidence, is that these represent the forms in which the proteids are absorbed. True, leucin, tyrosin, etc., further end products of proteolysis, are formed, but these cannot be absorbed. The opinion that *proteoses and peptones* are the absorbable forms of proteids is correct, for by far the largest part of these foods are absorbed in this shape. It is supposed also that syntonin at least can itself be sparingly absorbed from the alimentary canal, while the phenomena of rectal absorption would point to the conclusion that proteid absorption in other shapes is possible. Practically, however, proteoses and peptones may be regarded as the products of proteid digestion, and their production as the object of proteolysis.

But, although these substances are absorbed by the blood-vessels, the artificial injection of them into the veins occasions untoward effects, or at least their rejection through the organs of

excretion. Furthermore, proteoses and peptones cannot be detected in the blood during alimentary absorption. It follows, then, that *in their passage from the alimentary canal to the blood they undergo some change whereby they lose their identity and are no longer recognizable as such.* It is claimed that they are converted into **serum-albumin,** and this is probably true. One effect at least of the change is that they are now (in the blood) less diffusible, more complex, and consequently remain more easily a constituent part of that fluid.

The proteids enter the radicles of the portal vein.

3. *Carbohydrates.*—The sugar of the blood is dextrose, and if cane sugar be introduced into the veins it is rejected by the urine without being changed. It may be said that, with a few exceptions, all the carbohydrates are converted into *dextrose* or dextrose and levulose, before entering the blood. This form of sugar is easily oxidized in the tissues. It is conveyed directly to the liver by the portal vein.

4. *Fats.*—The digestive end of the fats has been seen to be *emulsions* and *soaps.* They pass into the intestinal lymphatics, or lacteals. Their absorption is a mechanical process. They enter and pass through the epithelial cells and basement membrane of the villus. Having thus passed into the stroma of the villus, their entrance into the lacteal is easy; for undoubtedly lymph spaces in the stroma are connected with the stomata of the central lymph capillary, and there is a more or less constant flow of lymph through these spaces toward the lacteal. The tendency, therefore, of the fats to enter the lacteal is physically natural. It is a curious fact that the peptones and sugars, having penetrated the lining epithelium of the villus, enter the blood instead of the lymph capillaries.

A number of circumstances, such as the rate of absorption, the persistent direction of the current toward the blood in the face of superior pressure, the disappearance of non-osmotic substances from the canal, etc., are frequently at variance with

laboratory experiments. Application of the laws of osmosis to the vital processes is seemingly subject to many variations, and explanation of many of the phenomena of absorption in the body waits upon a clearer understanding of the so-called "vital activity" of the tissues.

CHAPTER VIII.

NUTRITION, DIETETICS AND ANIMAL HEAT.

(A) NUTRITION.

All the processes of the body as digestion, absorption, secretion, circulation, respiration, etc.— have a single object, viz., *the nutrition of the cells of the body.*

The ulitmate source of all nutriment is, of course, food and oxygen. The oxygen has been followed from the lungs to the tissues as oxyhemoglobin of the blood. The various foods have been seen to disappear from the digestive tract and to be conveyed to the tissues by the great nutritive fluid, some in recognizable and some in unrecognizable form. If, now, we shall be able to discover in what way these different materials thus furnished the cells are utilized and appropriated by them, and in what condition they subsequently escape from the system, the study of nutrition will have been rendered much clearer. The intake is through the lungs and alimentary canal; the output is mainly by the lungs, skin, kidneys, and intestines. To show for the changes which take place while the food is in the body there is the growth of the body, the maintenance of tissue integrity, secretion, heat, motion and nervous energy.

It may be said at once, however, that the exact method of appropriation of nutritive material by the tissues is a subject of speculation, since it involves the question of life itself; and we shall have to be content with recounting some of the conditions influencing and some of the phenomena attendant upon the process.

Metabolism.—By *metabolism* is meant those processes in the

body whereby food products are appropriated, their stored-up energy utilized, and the waste discarded.

Metabolism is divided into, (1) anabolism, and (2) katabolism. *Anabolism* is the process of building up tissue by cell appropriation of food stuffs. *Katabolism* is the process of destroying tissue in order to set free energy that the organs of the body may perform their various functions.

When the anabolic processes are equal to the katabolic there is no excessive storage of material, but an individual remains of uniform size, weight, and strength. If the anabolic are in excess of the katabolic processes, the excessive products are stored up in the cells and an individual increases in size, weight and strength. If the katabolic processes are in excess of the anabolic there is a call on the tissues for the matter already stored there and there is a decrease in strength, weight and size.

Death.—As long as a cell appropriates enough to supply the deficit caused by the destruction of material in the expenditure of energy, the cell will live; but when the intake cannot make up for the output lost the cell ceases to functionate and this is called *death*.

Problems Involved in the Nutritive Process.—Since the actual changes occurring and the method of their production cannot be understood, the question of nutrition resolves itself into a consideration of the final fate of the various aliments, of their relative value in nutrition, of conditions influencing the process, and of the explanation of certain facts connected with the destruction of the food-stuffs, particularly the production of heat.

The change which the foods finally undergo in the body is one of **oxidation.** It is therefore chemical changes which give rise to physical activity. Oxidation is accompanied by the production of heat. The same sum total of heat is developed when a piece of iron rusts completely away in five years as when it is consumed in an atmosphere of oxygen in five minutes. In both

cases it is oxidized. In the cell oxidation is continually going on with the production of heat and of certain excrementitious (oxidation) products depending on the kind of food stuffs.

Fate of Different Foods in the Organism.—In the first place, the foods may be divided, into (I) those which *pass through the organism unchanged* and (II) *those which lose their identity* and are discharged as bodies different from those which entered. The first class includes the foods furnishing no energy; the second those furnishing energy.

(I) Attention has been given to the foods furnishing no energy as constituents of the body in Chapter I and reference should be made to that chapter for a discussion of the most important of them.

Only a few undergo in the body reactions which alter their identity. They may be regarded as already digested and, in fact, when dissolved, ready for discharge from the body. They are, however, useful and necessary constituents of the body, and if they do not take a considerable active part in nutrition, their favorable influence on that process makes them essential to health. The foods producing no energy may be dismissed with a repetition of the statement that they are largely introduced in connection with the proteid foods from which they cannot be separated without destruction of the proteid molecule. Indeed, all the proteid food introduced, whether animal or vegetable, contains inert constituents as a part of the molecule, and these seem as necessary to nutrition as do the energy furnishing constituents. The foods furnishing energy and those furnishing no energy enter, are deposited, and seem to be discharged both together. The few reactions which the inert foods undergo in the body do not materially affect the supply of energy.

(II) The *proteids*, *carbohydrates* and *hydrocarbons* are all consumed in the organism, none (unless they have accidentally escaped digestion) being discharged as they entered.

1. The **nitrogenous** foods are changed into peptones in the

alimentary canal, undergo some unknown change in their absorption therefrom, appear in the blood as the proteid constituents of that fluid, and are offered to the tissues through the medium of the lymph. The complex proteid molecule is broken down into simpler but more stable ones. These end products are **carbon dioxide, water** and **urea,** together with some sulphates and phosphates, the production of which is comparatively immaterial. The urea is distinctive. **Heat,** which is equivalent to so much energy, is evolved in the oxidation process.

It is probable that not all the proteid, under the ordinary diet, is actually built up into cell substance. A part of it seems to be destroyed without being transformed into protoplasmic material, but the destruction always takes place through the agency of the cells, and the end products are always the same, whether disassimilation of the proteid occurs with or without its becoming an intrinsic part of the cell.

Nitrogenous Equilibrium—Circulating and Tissue Proteids.— The fact, however, that the characteristic function of the nitrogenous foods is to furnish protoplasmic material should not be lost sight of. A certain amount is necesary to maintain "nitrogenous equilibrium;" that is, to keep the intake of nitrogen up to the output. When nitrogenous food is withdrawn there continues to be a discharge of urea, which is the chief nitrogenous excretion and the amount of which represents the amount of nitrogenous disassimilation in the body. The urea eliminated under these conditions must represent the actual destruction of cell substance, and, since the supply is zero and the output is considerable, there is not a state of nitrogenous equilibrium; the animal is suffering destruction of its protoplasm without a compensatory constructive process. On the other hand, the supply of nitrogenous material may be, and usually is, in excess of the demands of the cells for the actual regeneration of their substance. This excess may be termed "*circulating proteid,*" and is that just referred to as being oxidized under the influence of the cells, but

without being transformed into protoplasm. That part of the nitrogenous supply which is built up into a part of the cell has been called "*tissue proteid*." Whether any given molecule of proteid food pass through the system as circulating or tissue proteid is only an accident—provided the supply be above the demand of the cells for tissue proteid; these demands are the first to be supplied by the nitrogenous material at hand.

From this it is not to be inferred that the exigencies of nutrition will be met as well without as with circulating proteid. When the diet consists of just enough proteid to supply the tissue wastes and of ample carbohydrate and hydrocarbon materials, the nutritive process is impaired. It seems necessary to perfect health that the supply of nitrogenous food be sufficient to allow for the oxidation of some of it as circulating proteid in a manner analogous to oxidation of the non-nitrogenized materials. Life can be maintained on nitrogenous food alone, but it is obvious that when this is done the amount of circulating proteid must be enormously increased so that it may be oxidized to furnish energy for the body; for those substances, the oxidation of which corresponds to oxidation of the circulating proteids and which furnish the main supply of energy for doing work (viz., the carbohydrates and hydrocarbons), are now withdrawn from the economy. It follows, conversely, that the ingestion of carbohydrates and hydrocarbons lessens the amount of proteid necessary to nutrition.

The *albuminoids*, such as gelatin (not meant to be included under the term "nitrogenous" foods, though they contain nitrogen), cannot take the place of *tissue proteid*; they may be burnt *in lieu of the circulating proteids* and supply energy just as the carbohydrates and fats do.

It is to be remembered that any excess of proteid or albuminoid food is *not* discharged as such in the excreta, but undergoes oxidation, the end products of which are always the same, water, carbon dioxide and urea, or related substances; the develop-

ment of heat is also an invariable accompaniment of their destruction.

While a person may live on proteid food, the amount necessary taxes the digestive and excretory organs to such an extent that life is probably shortened. Since the total amount of urea is discharged by the kidney, that organ, under an excess of proteid diet, is particularly prone to degenerative changes of a most serious nature.

2. The **carbohydrates** enter the blood from the alimentary canal as dextrose, are conveyed to the liver and converted into glycogen, which is stored up there to be dealt out to the blood gradually, after being reconverted into dextrose. Dextrose exists in the blood for a short time only, being converted into other substances, but its final oxidation is effected by the tissues. Its end products are **carbon dioxide** and **water,** with **heat.** Sugar (dextrose) injected into the blood soon disappears. It is thought by some to be converted into alcohol in the blood and then oxidized. At any rate, the formation of the end products just mentioned is the final fate of the carbohydrates, through whatever splitting processes the sugar molecule may pass before it is converted into these substances.

The removal of the pancreas occasions diabetes mellitus, and the inference is that this gland gives off to the blood some internal secretion which splits up the sugar molecule in the blood. How this lesion causes the disease in question is not clear, but the retention of a small part of the gland enables the oxidation of sugar by the tissues to proceed in the proper way and it is not discharged in the urine.

Value of the Carbohydrates in Nutrition.—The distinctive function of the carbohydrates is to act as fuel for the body machine; they are burnt up to supply heat, and heat represents energy. Hydrogen and oxygen exist already in the proportion to form water—one of the end products—and only enough O is required to unite with the carbon of the carbohydrates to form

CO_2—the other end product. The burning (oxidation) of a carbohydrate outside the body results in the formation of CO_2 and H_2O and the elimination of heat, which last, if properly utilized, can be converted into energy—the power to do work. The result of the oxidation of a carbohydrate in the body is the same. Since this class of food is easily handled by the alimentary canal, requires little extra O for its destruction, and is very abundantly supplied by the vegetable world, it is the most economical from digestive, absorptive, respiratory and financial standpoints. Carbohydrates may also be deposited as adipose tissue as will be seen presently.

3. The **fats** have the same general office in nutrition as the carbohydrates, viz., the furnishing of energy by their oxidation. They leave the alimentary canal by way of the lacteals, are conveyed by the blood to the tissues and there oxidized with the formation of **carbon dioxide** and **water** and the liberation of **heat.** Though more O is necessary to burn up the fat than the carbohydrate molecule, oxidation of the fat is attended with the liberation of the greater amount of heat—*i. e.*, of energy. This would seem to indicate that it would be more economical to eat fats to the exclusion of carbohydrates, since a smaller quantity of the former will supply the requisite amount of energy. This is theoretically true, but considerations of digestion render it not practically so; fats tax the digestive apparatus much more than carbohydrates.

The fat deposited in the body—the adipose tissue—whatever may be its source, is to be looked upon as so much stored-up energy. When the supply of blood is cut off it is the first part of the organism to be consumed. A fat animal will survive starvation longer than a lean one.

The individuality, the functional activity, and the properties involved in regeneration of protoplasm are ultimately dependent upon its *nitrogenous* characters. The other constituents are more or less passive. The oxidation of fats and carbohydrates,

however, takes place under the influence and through the agency of the cells. It is scarcely necessary to add that neither fats nor carbohydrates, nor both together, are sufficient to sustain life; for life is embodied in protoplasm and protoplasm must have nitrogen, which element these foods cannot furnish.

Formation of Adipose Tissue.—The adipose tissue in the body is not the result of direct deposition of the oleaginous foods. The amount of fat taken on in a given time by some animals, as hogs, is often far in excess of the quantity of fat in the ingesta. Adipose tissue is, under normal conditions, the result always of changes due to protoplasmic activity. It is formed by the tissues chiefly from the **carbohydrates,** but also to a less extent from the proteids. The chemical changes by which sugar is converted into fat are as yet undetermined, but there are so many evidences of an increase in body fat upon an excess of carbohydrate food that the fact itself that this class of food is the main source of fat is no longer disputed.

As regards the formation of fat from *proteids*, it is thought that the molecule is split up into a nitrogenous molecule, which is discharged as urea, and a non-nitrogenous, which at once, or after undergoing other changes, is deposited as fat. Experimental observations demonstrate that the liver produces glycogen on a purely proteid diet. Since glycogen is a carbohydrate, and carbohydrates are the chief source of body fat, it is not improbable that the non-nitrogenous molecule of the proteid dissociation takes the form of glycogen and is later converted into fat after the manner, whatever it may be, of the glycogen introduced in carbohydrate form. When the carbon discharged is less than the carbon ingested the deficit is thought to be retained to form fat, which is deposited as a reserve to be used whenever its oxidation may become necessary as a supply of energy.

It follows that to reduce body fat the carbohydrates should be largely interdicted, while to increase it they should be taken in excess. In human beings proper regulation of the diet is more

efficacious in reducing than increasing the amount of adipose tissue.

Adipose Tissue a Reserve Supply of Energy.—The carbohydrates and fats are preëminently the energy-producing foods, and of these the carbohydrates, for reasons indicated, are the more important. They not only furnish energy which is immediately used up in running the machinery of the body, but they deposit, or attempt to deposit, a reserve supply to *protect the proteid* portions of the organism against accidents of temporary deprivation of food, demands for an unusual amount of energy, malnutrition from various causes, etc.—savings laid for the proverbial rainy day. This reserve supply takes the form *first* of glycogen, which is soon used up, meeting as it were only the demands of the hour, and *second* of fat, which begins to be drawn upon when the glycogen is exhausted, and which lasts for a length of time depending upon its amount.

Conditions Influencing Metabolism.—Regular **exercise** is undoubtedly favorable to the nutrition of any part, as *e. g.*, the muscles, the brain, etc. Exercise may mean increased disassimilation, but if so it also means increased assimilation. With regard to muscular exercise of average severity and reasonable duration, the results of cellular activity seem at first a little surprising, but are really to be expected if the concluding remarks of the previous paragraph are true. The amount of urea under such exercise is not appreciably increased—which means that disassimilation in the protoplasm of the muscle cells is not increased. This remark holds good, however, only when the supply of sugars, starches and fats is abundant; if they are not present in sufficient quantity to meet the increased demand for energy-supplying materials, then the proteids must be oxidized to furnish it, and the urea discharge is increased. In striking contrast to the constant output of urea is the largely increased output of CO_2, representing oxidation of the carbohydrates and fats.

During **sleep** the nitrogenous output it not materially diminished, while that of CO_2 is markedly less. This is explained by the fact that there is less energy needed and correspondingly less oxidation of the energy-producing materials. Proteid metabolism is undisturbed.

A **low external temperature** does not increase the output of urea; it increases the output of CO_2. These two facts together mean again that only the carbohydrates and fats are being oxidized in increased amount. This increased oxidation, the effect of which is to maintain the normal body temperature is usually dismissed with the statement that it is a reflex nervous act. It is claimed by Johannson that the CO_2 output is not increased until *shivering* occurs (Reichert). That being the case, the increase is explained on the ground of increased energy and heat production incident to muscular exercise, and shivering assumes the dignity of a physiological factor in keeping up the temperature of the body. This is perfectly reasonable when it is remembered how effective active muscular exercise is in keeping the body warm. But the fact that a person when cold shivers and is restless *involuntarily* does not allow us to escape the unsatisfactory "reflex action" explanation of the phenomenon in question. Within ordinary and reasonable limits proteid metabolism is undisturbed; it is still being protected by the fats and carbohydrates.

During **starvation** nothing is supplied from the outside world except oxygen, and the animal must live on the materials already in his body. The glycogen is first consumed; it is the surplus on hand; but at best it is all gone in a very few days. Then the fat stored up as adipose tissue is drawn upon; it is the reserve fund; but it is likewise soon consumed; the animal becomes progressively emaciated. When this is exhausted the tissue proteid is attacked; this is the capital and is the last to be touched; but there must be heat and at least some energy, and there is no other source. When the proteid capital has at last been so impaired that it can no longer furnish heat to maintain

the body temperature and energy to carry on the necessary organic functions, the organism is physiologically bankrupt and assignment follows—death is at hand.

(B) DIETETICS.

The appetite, under normal conditions, may be depended upon to regulate both quantity and quality of diet in a fairly satisfactory manner. Different peoples require different proportions and amounts of the various food-stuffs and the same is true of any given individual for varying conditions of temperature, exercise, etc. But in any case the object of eating is to prevent the loss, in aggregate, of proteid tissue, fat, etc.—to replace the wastes, and that in the most convenient and economical way.

When the ingesta exceed the excreta the animal is gaining in weight; when opposite conditions obtain he is losing; when there is a balance between the two the body equilibrium is being maintained.

Determination of the Requisites of a Diet.—The usual method of determining, in a scientific manner, the requisites of a normal diet for perons in general is to estimate the amount of the various *excretions* from the bodies of a limited number of persons in health, and from this knowledge to calculate the amount and kind of food which will supply the demands in the most satisfactory way, it being assumed that these excretions represent the normal and necessary metabolism going on in the body. The results of such examination are found to correspond with the actual demands of the system.

It has been seen that the organism demands some fifteen or more chemical elements for use to keep itself in good running order; it has been seen also that its demands, so far as quantity is concerned, are chiefly confined to carbon, hydrogen, oxygen and nitrogen. The other elements deserve no attention here since they (excepting sodium chloride) are unconsciously introduced with the ordinary foods in amounts sufficient to satisfy the re-

quirements of the system. Moreover, the air we breathe and the water we drink furnish an ample supply of hydrogen and oxygen when to this supply is added the quota of these elements contained in the necessary quantities of other aliments. So, therefore, if we fix upon a diet which will furnish the requisite amounts of **carbon** and **nitrogen** no attention need be paid to the other elements. The supply of the others may be said to regulate itself if the supply of carbon and nitrogen be regulated.

The object, then, of food may be said to be the replacement of carbon and nitrogen—the carbon and nitrogen in the excreta. Of these two elements, carbohydrates and fats will furnish only carbon; proteid food will furnish both.

Amount of C and N Necessary.—It is found that the daily discharge of nitrogen is about 18 grams (4½ ʒ) and of carbon about 281 grams (8½ ℥). These are the amounts, therefore, which, must be supplied by food. We may accept, as representing the proteid molecule in general, the formula $C_{72}H_{112}O_{22}N_{18}S$. Then it is evident that an amount of proteid food which would furnish the necessary 18 grams of nitrogen would furnish only 72 grams of carbon—only about one-fourth enough. If, now, the proteid food be increased to supply 281 grams of carbon, the system will have to handle four times as much nitrogen as it needs; and this is a tax to the digestive apparatus and the excretory organs, particularly the kidney—a tax which is rendered unnecessary by the availability of the carbohydrates and fats as food. These contain abundance of carbon, and it is far better to eat only enough proteid food to supply the 18 grams of nitrogen, and make up the deficit of carbon with non-nitrogenized articles of diet. *One can supply all the demands by eating nitrogenous food alone, and life will be preserved indefinitely perhaps, but the prediction would be warranted that in such a case the person would probably die prematurely—as a result of kidney or liver disease.*

Articles Which will Supply the Necessary Amounts of C and N.—The conclusion (modified) of Moleschott is that

the average man needs daily about 120 grams of proteid, 90 grams of fat, and 320 grams of carbohydrate food, estimated dry; and that with this, in the usual state in which such food is taken, he will consume unconsciously, or as a result of craving, some 30 grams of salts and 2,800 grams of water. These proportions are supposed to satisfy the demands of the system in an economical way. The estimates of Ranke vary somewhat from this as indicated in the subjoined table which shows also the *balance* kept up in the body.

Income.			Expenditure.		
Foods.	Nitrogen.	Carbon.	Excretions.	Nitrogen.	Carbon.
Proteid 100 gm.	15.5 gm.	53.0 gm.	Urea 31.5 gm.	14.4	6.16
Fat 100 "	0.0 "	79.0 "	Uric acid 0.5 "		
Carbohydrates 250 "	0.0 "	93.0 "	Feces	1.1	10.84
			Respiration (CO_2)	0.0	208.00
	15.5 "	225.0 "		15.5	225.00

The actual amounts of given substances which it is necessary to eat in order to supply the requirements of these estimates depend, of course, on the composition of those substances, and would have to be settled by reference to a table giving analyses of the common articles of diet. Two pounds of bread and ¾ pound (when uncooked) of lean meat, together with water and salt, will supply the demands; but this is an unusual diet. Or 1 pound of meat, 1 pound of bread and ¼ pound of butter, or other fat, with water and salt is probably preferable.

In any case if nutrition is to be properly performed the diet must be *varied*. It could not be held that the above supply of food would keep a person indefinitely in good health. His demands for nitrogen and carbon are always approximately the same, but the organism revolts at being supplied with them from exactly the same source for any considerable length of time.

As a diet is necessary (Schenck & Gurber):

	Proteid.	Fat.	Carbohydrates.
Resting man	100 gm.	60 gm.	400 gm.
Resting woman	90 "	40 "	350 "
Working man	130 "	100 "	500 "

It need scarcely be added that any condition, such as exercise, temperature, etc., which increase the excreta, calls for a larger supply of ingesta. Ordinary exercise is allowed for in the estimates just given.

(C) ANIMAL HEAT.

The Temperature.—The average temperature of the human body, taken under the tongue, is 98.5° F. It varies in different parts, the mean being about 100°. The metabolic activity in different parts of the body is changeable, and consequently the heat production in all parts is not the same.

The fact that the temperature is nearly identical throughout the body is due to the *distribution* of heat, which distribution is mainly effected through the agency of the circulating fluids. The rectal temperature is a little higher than that obtained in the mouth. The temperature of arterial is higher than that of venous blood. The warmest blood is in the hepatic veins; the coolest is that which has just passed through the most exposed peripheral parts, as the helix of the ear. The mean body temperature is a little lower in the morning than in the evening, in the female than in the male, on a restricted than an an abundant diet, in cold than in hot climates, and, in general, in conditions of diminished than of exalted metabolic activity.

But in health these variations are of trivial importance and do not represent a sweep of more than 2° F. The body temperature may be looked upon as being a fairly constant quantity. It varies scarcely at all with variations of external temperature, so long as the heat-regulating apparatus is in order. An external (dry) temperature of 212° F., or the extremely low temperature of some regions, can be borne with very slight fluctuations in

that temperature of the body. The actual limits of internal temperature consistent with the preservation of life are given by Flint as 83° and 107° F. These temperatures cannot be long endured.

The fundamental fact to be kept constantly in mind is that there is a continual *production* and a continual *dissipation* of heat, in ways to be indicated presently. These two processes are known as *thermogenesis* (heat production) and *thermolysis* (heat loss) respectively. The preservation of the proper balance between heat production and heat dissipation is known as *thermotaxis*.

Supply of Heat and its Relation to Force.—It is a matter of common observation that the burning (oxidation) of any substance, as a piece of wood or an article of diet, is accompanied by the evolution of heat. It is also known that heat may be converted into force—may be made to do work. The burning of a fat or a sugar produces CO_2 and H_2O; the burning of a proteid produces CO_2 and H_2O, and additional substances. The final products, and the amount of heat evolved, are precisely the same whether the oxidation be rapid or slow. Now, the oxidation of food is exactly what occurs in the human organism, though that of the proteids is not completely effected; CO_2 and H_2O are produced from them, and the "additional substances" mentioned are represented by urea. This process, then, is the *source of body heat*. To the supply thus furnished may be added a little from reactions between non-energy producing materials in the body, from warm foods and drinks, and from friction in the vessels, joints, etc.

The foods thus possess a certain *potential energy*, an energy which may be converted directly or indirectly into heat, or its equivalent. The potential energy of the foods keeps up the body temperature and supplies force for doing work. It is converted into *heat and kinetic energy*. Kinetic energy is working energy, and is represented in the body chiefly by muscular con-

tractions. But, since this kinetic energy has its source in the transformation of food stuffs, and since kinetic energy and heat are mutually convertible, it may be assumed that all the potential energy of the foods is converted into heat. The kinetic energy may be taken as representing so much heat, and the total production of heat (including kinetic energy) as representing the total production of energy. Or, to state the case differently the potential energy of the food is converted into heat, a part of which appears as kinetic energy. By far the largest part of this potential energy, however, is converted directly into heat. Not more than *one-fifth* of the heat produced in the body can be utilized to do *work*, and a part of that work is actually converted indirectly into heat, and contributes to the total heat of the body, by overcoming friction incident to respiration, circulation, movements of the joints, muscles, etc.

Potential Value of Foods.—It is estimated that the oxidation in the body of one gram of *fat* produces 9,300 calories of heat, one gram of *carbohydrate* 4,100 calories, and one gram of *proteid* 4,100 calories. These figures represent the potential energy of the several foods. Fats, it is seen, produce, weight for weight, more than twice as much energy as other foods, but reasons have been given why they cannot be used exclusively.

A *calorie* is the amount of heat necessary to raise 1 Kg of water from 0° to 1° C. A *grammeter* is the amount of energy necessary to raise 1 gram 1 meter. Now since heat and work are only different forms of energy, these two units—calorie and grammeter—have each equivalents in terms of the other. One calorie equals 424.5 grammeters; that is, the force represented by one calorie will raise one gram 424.5 meters. The terms kilocalorie, or kilogramdegree, and kilogrammeter are used sometimes, and represent 1,000 times the calorie and grammeter respectively.

Total and Specific Heat.—The temperature of a body indicates nothing as to the quantity of the heat it contains. The

degree of heat requires only a thermometer to determine it, but the *quantity* depends on the temperature, the weight and the specific heat of the substance in question.

Specific heat is analogous to specific gravity. Water is taken as the standard in both cases. If it require only .5 calorie to raise 1 gram of a certain substance 1 degree C., the specific heat of that substance is said to be .5. The specific heat of the body is .8; that is, whereas it requires a certain amount of heat to raise 150 pounds of water to a certain temperature, it would require only .8 as much to raise a human body weighing the same to the same temperature. To find the *total heat* in calories in any body it is only necessary to multiply the weight (in grams) by the specific heat and by the temperature C. Estimates made by calorimetry from these data and from the potential value of the different foods give the total daily heat production as about 2,500,000 calories for the average individual. This is equal to about 1,400 calories per hour per kilo weight.

The English heat unit is the *pound-degree F.* It is the amount of heat necessary to raise 1 pound of water 1 degree F. Its mechanical equivalent is the force necessary to raise 1 pound 772 feet. The estimates just given in the metric system when translated to English nomenclature give the total heat production for 24 hours as about 8,400 pound-degrees, or 2.5 per hour per pound weight. These figures are given as only approximate and are subject to change by many causes, such as sex, cardiac and respiratory activity, internal and external temperature, exercise, digestion, age, nervous influences, the body weight, etc.

Thermogenesis.—Thermogenesis, or the production of heat, is the result of activity on the part of tissues, nerves and centers. Now, the potential energy of the food stuffs is the ultimate source of all bodily heat no matter how it may be manifested, and it is evident from what has been said already that all the tissues of the body are heat-producing tissues, because oxidation

processes go on in them all. But *muscular tissue* seems to be endowed with special heat-producing capabilities, so much so that it is said to generate heat as a *specific product*, and not as a mere incident of its metabolism. Muscle will reproduce heat when entirely at rest—when the nutritive metabolic changes are practically nothing. The process seems to be regulated in accordance with the needs of the economy by means of a nervous mechanism, making the production of heat analogous to secretion. Separation of a muscle from its nerve does not stop thermogenesis, but markedly interferes with it in that part. The existence of distinct thermogenic nerves has not been demonstrated. The existence of specific thermogenic centers seems certain. Some of them increase and some decrease thermogenesis.

The general thermogenic centers are in the spinal cord. Centers increasing thermogenesis are probably in the caudate nuclei of the corpora striata, the optic thalami, pons and medulla. Irritation of these regions causes a rise in temperature. The location of the thermo-inhibitory centers is a matter of speculation. The general thermogenic centers in the cord probably maintain a fairly constant production of heat independently, but they are subservient to encephalic centers which excite them to increased or decreased activity by reason of certain impressions, cutaneous or otherwise, which they have received.

Heat Loss.—About 85 per cent. of animal heat, discharged as such, is lost by radiation and evaporation from the *skin;* about 12 per cent. is dissipated in the *lungs* by evaporation and in warming the inspired air; the remainder is discharged in the *urine* and *feces* (disregarding the small amount which goes to warm ingested articles).

Heat is **radiated** from the body just as from a hot stove. Radiation is affected by the conductivity of the surrounding medium. For instance, in media of water and air of the same temperature the radiation is greater in water, because it is a better conductor of heat.

Evaporation from the skin is of very great importance in increasing heat dissipation. 582 calories of heat are consumed when one gram of water is vaporized; and when this evaporation takes place on the skin the heat is abstracted largely from the body. This is said to represent nearly 15 per cent. of the total heat dissipation. Hence the value of perspiring in hot weather. Evaporation also takes place from the moist surfaces of the lungs and, moreover, when, as is usually the case, the inspired air is cooler than the lung structure, a certain amount of heat is consumed in warming it.

But it is not to be inferred that loss of heat takes place from the body just as from an inanimate object. On the other hand, it is intimately connected with and influenced by *circulation*, *respiration*, *secretion* and other functions. When there is a tendency for the body temperature to rise, the circulation becomes more active and sends more blood to the periphery to be cooled; respiration is augmented, causing a greater abstraction in the lungs; the secretion of sweat, for instance, is increased.

There may be distinct **centers** governing the loss of heat.

Conditions Influencing Heat Dissipation.—These have been suggested in a previous section. Heat dissipation is greater in proportion to weight in *small* than in *large* animals because the radiating surface is relatively larger. It is less in the *female* than in the *male* because she has, as a rule, a larger proportion of subcutaneous fat, which is a poor conductor of heat. It is less when the body is covered with *clothing* which is a poor conductor of heat than when the covering conducts heat readily. It is increased when the *internal temperature* is raised and when the *external temperature* is lowered. Any general increase in *vascular* or *respiratory activity* increases heat dissipation for reasons already given. When the *external temperature* is high and the *air is dry* evaporation is more abundant, and consequently heat dissipation is greater than when the air is already impregnated with moisture. Hence the oppressiveness of a

high external temperature with high humidity. In *fever* heat dissipation is usually increased, but to a less degree than heat production.

Thermotaxis.—Thermotaxis is the *regulation* of heat production and heat dissipation so that the temperature of the body may remain the same. It is evident that there is frequently a transient increase or decrease of thermogenetic activity; unless there be a corresponding change in thermolytic activity the temperature will be disturbed.

The temperature of the body is not necessarily raised when heat production is increased, or lowered when it is decreased; for heat loss may be, and in health is, correspondingly increased or diminished. Conversely, a change in heat loss does not necessarily mean an opposite change in the body temperature. Alterations which do occur in the temperature are the result of the improper *regulation* of the heat at hand. For instance, fever may result from average heat production and deficient heat loss; from increased heat production and heat loss when the latter is increased less than the former; from diminished heat production and heat loss when the latter is diminished less than the former, etc. A subnormal temperature is caused by opposite conditions. The temperature remains constant when heat production and loss are normal, or when they are increased or decreased correspondingly.

Thermotactic activity is the result of changes in the *temperature of the blood*, or of *cutaneous impressions.* A rise in the temperature of the blood excites heat loss, as indicated. A cold atmosphere increases heat loss, but at the same time it makes impressions on the cutaneous nerves which, when carried to the centers, excite heat production and thus compensation is established. A cold bath lowers the temperature because heat loss is increased more than heat production. There is increased radiation because of the relatively increased difference in the temperature of the body and of the surrounding medium. On the

other hand, the cold contracts the capillaries, diminishing the amount of blood exposed to the cooling influence of the water and decreasing the amount of sweat; but these influences tending to inhibit heat loss are not equal to those augmenting it. However, in health, thermotaxis prevents the disturbance of the *balance* between thermogenesis and thermolysis to any great extent, and the temperature cannot be lowered very much. These are only examples of the reciprocal relations maintained between the production and dissipation of heat, a disturbance of which relations is prevented under normal conditions by thermotaxis. Any change in one process is followed at once by a compensatory change in the other.

CHAPTER IX.

EXCRETION BY THE KIDNEYS AND SKIN.

Excretion of the various foods after they have discharged their several functions in the body is effected mainly by the *kidneys*, *skin*, *lungs* and *alimentary canal*. The excretory action of the last two named is considered under Respiration and Digestion. Attention is again called to the fact that it is impossible to differentiate strictly between a secretory and excretory fluid. The urine is as typical of the excretions as any fluid to be found. But it will be convenient to speak of the "secretion" of urine when reference is made to the act of separating its constituents from the blood.

The Kidneys.

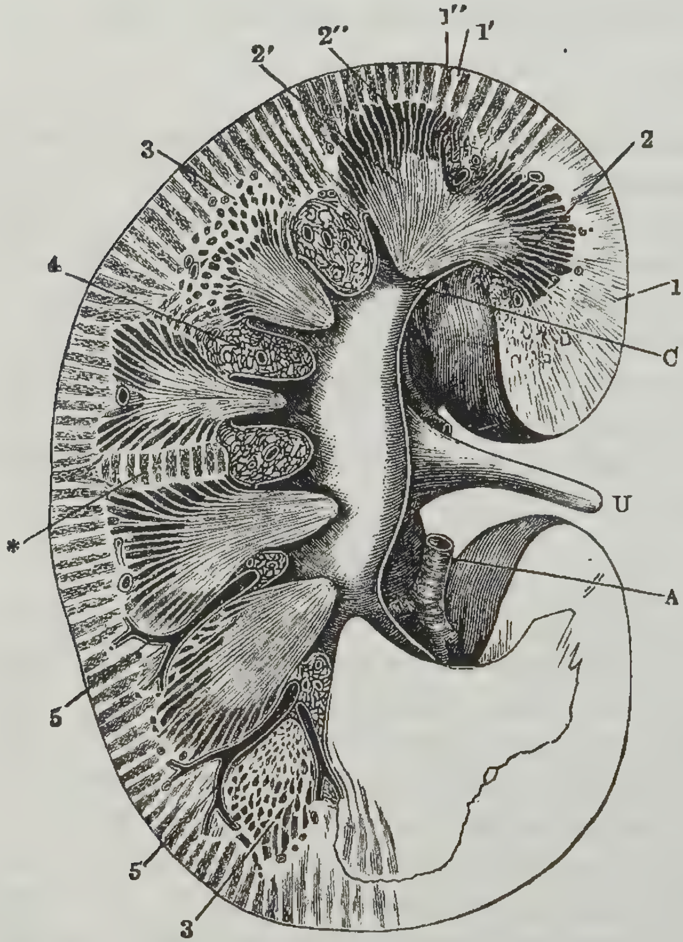
Anatomy.—The kidneys, one on each side of the body, are behind the peritoneum in the lumbar region. The right is usually a little lower and a little lighter than the left. The *hilum* from which the ureter springs looks inward and forward. The kidney, as found behind the peritoneum, is covered with a considerable amount of fat, but the substance proper of the organ is closely surrounded by a somewhat resistant fibrous capsule which in health can be easily stripped away. At the hilum the capsule is continued inward to line the pelvis, infundibula and calyces.

The kidney belongs to the class of compound tubular glands. If it be cut into two halves by an incision passing through the two borders (and, therefore, through the hilum) an idea of its gross divisions is obtained. The renal substance is seen to be divided

into an outer layer, known as the *cortical* substance, and an inner, or *pyramidal*, portion. Internally the incision reveals a cavity into which the ureter opens. This is the *pelvis*.

Tracing the divisions of the pelvis toward the kidney substance,

FIG. 50.

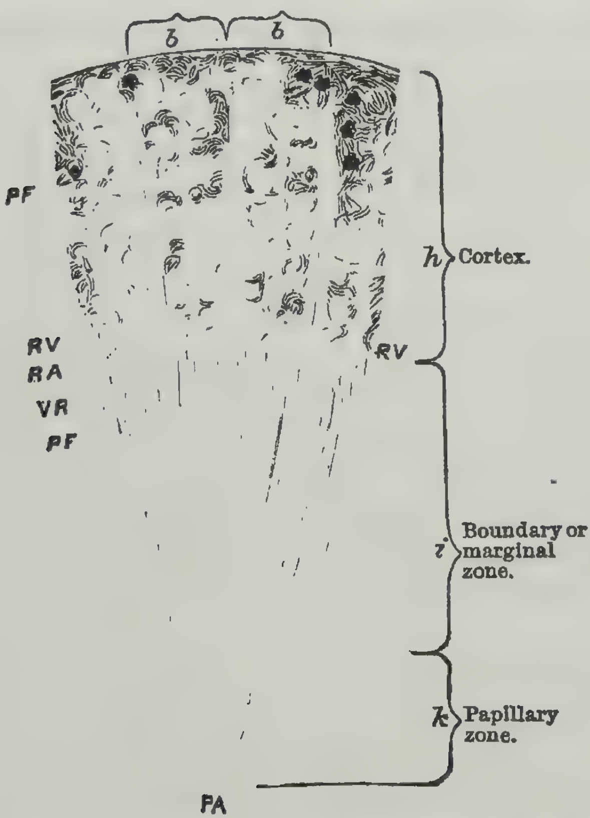


Longitudinal section through the kidney, the pelvis of the kidney, and a number of renal calyces. (From *Brubaker*, after *Tyson*.)

A, branch of the renal artery; U, ureter; C, renal calyx; 1, cortex; 1', medullary rays; 1'', labyrinth, or cortex proper; 2, medulla; 2', papillary portion of medulla, or medulla proper; 2'', border layer of the medulla; 3, 3, transverse section through the axes of the tubules of the border layer; 4, fat of the renal sinus; 5, 5, arterial branches; * transversely coursing medulla rays in column of Bertin.

it is found to be continued by three short canals, one towards the upper, one towards the lower and one towards the central portion of the organ. These are the three *infundibula*. Each infundibulum, passing outward, subdivides into two or three. or

FIG. 51.



LS, of a pyramid of Malpighi; *PF*, pyramids of Ferrein; *RA*, branch of renal artery with an interlobular artery; *RV*, lumen of a renal vein receiving an interlobular vein; *VR*, vasa recta; *PA*, apex of a renal papilla; *b*, *b*, embrace the bases of the lobules. (*Stirling.*)

more, short cylinder-like canals which receive the apices of the pyramids. These are the calyces, each of which receives the apex of one or more pyramids. The urine thus escaping from the pyramidal tubules passes in succession through the calyces, infundibula, pelvis, and thence into the ureter.

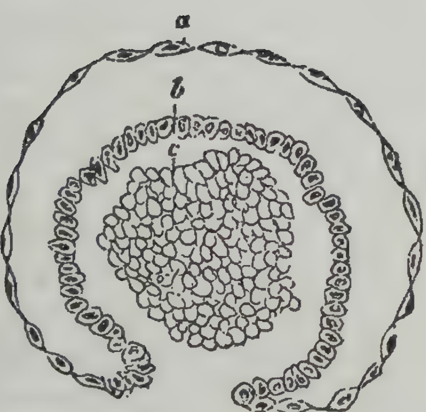
The **cortical substance** constitutes the outer layer of the kidneys and is about $\frac{1}{6}$ inch thick. It is reddish and granular in appearance. From it pass in between the Malpighian pyramids columns known as the *columns of Bertin*. The cortical substance contains the glomeruli and convoluted tubules together with blood-vessels and lymphatics supported by connective tissues.

The **pyramidal substance,** also called the **medullary substance,** consists of a number of pyramids, about 12–15, whose bases look outward and rest on the cortical substance and whose apices look inward and are received into the calyces. These are called the *pyramids of Malpighi*. They contain uriniferous tubules, vessels, etc., supported by connective tissue. It will be seen that these tubes converge and join each other in passing from the base to the apex of the pyramid, so that the very large number entering the base is represented by only 10–25 at the apex. Thus it is that the Malpighian pyramid is divided into a number of smaller pyramids. These latter are the *pyramids of Ferrein*, and correspond in number to the number of tubes radiating from the apex of the larger pyramid. The medullary substance is marked by striæ which have the direction of the tubules and which are caused by them. Its consistence is firmer and its color is darker than that of the cortical substance.

Malpighian Bodies.—These are scattered throughout the cortical substance, and are $\frac{1}{100}$–$\frac{1}{250}$ inch in diameter. They consist of a bunch of capillaries in the shape of a ball, the *glomerulus*, surrounded by the extremity, or rather the beginning, of one of the renal tubules. At the point where the tubule joins the Malpighian tuft it is constricted; running then over the glomerulus it reaches the afferent artery and the efferent vein on the opposite side; when it has reached these vessels it is reflected over the whole network of capillaries so that really the tuft is outside the tube, but practically it is covered by a double layer of the tube wall. A space, the beginning of the tubule, is left between

these two layers and into it the glomerular secretion passes. The outer layer is the *capsule of Bowman* (or Müller). Both layers consist of a single stratum of flattened epithelial cells; those of the inner layer are applied closely to the glomerulus and are thought to be very important in secretion. The incoming artery

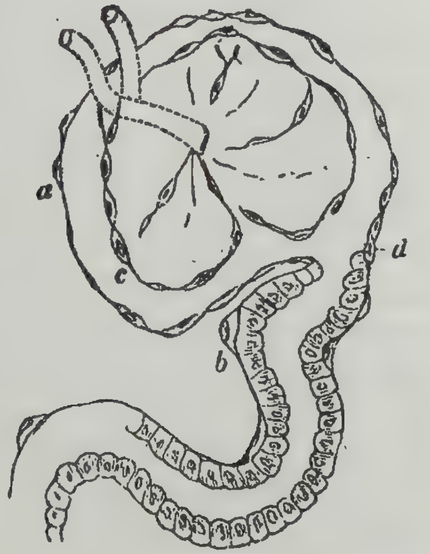
FIG. 52.



Transverse section of a developing Malpighian capsule and tuft (human). $\times 300$.

From a fetus at about the fourth month; *a*, flattened cells growing to form the capsule; *b*, more rounded cells continuous with the above, reflected round *c*, and finally enveloping it; *c*, mass of embryonic cells which will later become developed into blood-vessels. (*Kirkes* after *W. Pye.*)

FIG. 53.



Epithelial elements of a Malpighian capsule and tuft.

With the commencement of a urinary tubule showing the afferent and efferent vessels; *a*, layer of flat epithelium forming the capsule; *b*, similar, but rather larger epithelial cells, placed in the walls of the tube; *c*, cells, covering the vessels of the capillary tuft; *d*, commencement of the tubule, somewhat narrower than the rest of it. (*Kirkes* after *W. Pye.*)

breaks up to form the capillary tuft; the corresponding outgoing vein has a smaller caliber than the artery. The vein, having left the glomerulus, breaks up into a *secondary network* around the convoluted tubes. This arrangement of the Malpighian body furnishes a most favorable opportunity for the passage of sub-

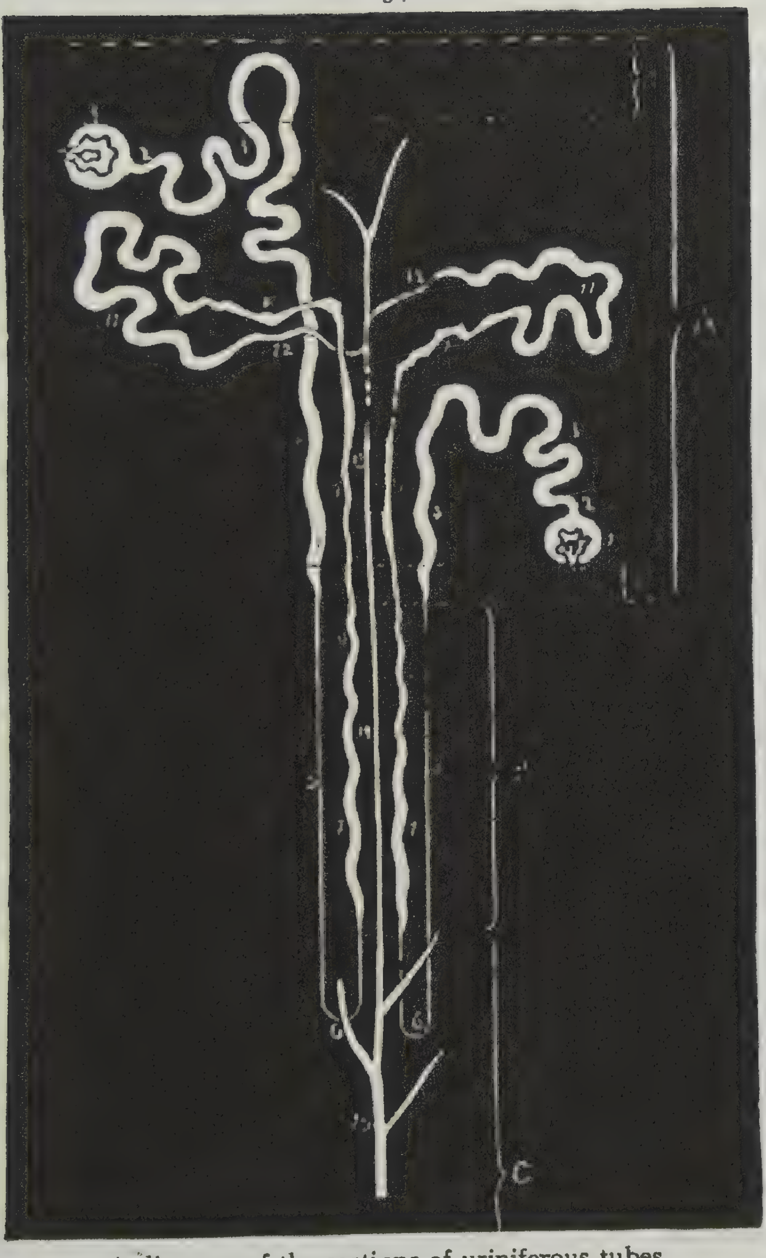
stances out of the blood current into the beginning of the tube.

Uriniferous Tubules.—These begin at the glomeruli and end at the apices of the Malpighian pyramids. From their tortuous course in the cortical portion they are there called *convoluted* tubules, in contradistinction to the *straight* tubes of the medullary portion. This, however, is only a general division; further the distinctions are to be noted.

The constricted portion of the tube where it leaves the glomerulus is the (1) *neck;* passing away from the neck the tubule becomes very tortuous and is known as the (2) *primary convoluted tubule*, which, having run for a variable distance, becomes narrow near the base of the pyramid, and taking a comparatively straight course downward enters the pyramid under the name of the (3) *descending limb* of Henle's loop; some of these run nearly as far as the apex, but most of them near the base or middle of the pyramid turn upward forming thus (4) *Henle's loop* and beginning the (5) *ascending limb* of Henle's loop; the tube having reëntered the cortical substance becomes convoluted again, (6) *secondary convolution*, which, by a less tortuous continuation, the (7) *intermediate tube*, communicates with the collecting tubules, or the (8) *straight tubes of Bellini;* these last beginning in the cortex, and receiving in their course large numbers of intermediate tubes, enter the base of the pyramid and run in a nearly straight direction toward the apex. About 100 of these straight tubes entering at the base join in their course downward until at the apex they are represented by a single tube. These collections constitute the pyramids of Ferrein; there are about 12–18 pyramids of Ferrein to each Malpighian pyramid, and as many tubal orifices at the apex. The so-called *zigzag* and *spiral tubules* are here considered parts of the first and second convoluted tubules. (See Fig. 54.)

Before they reach the collecting tubules the tubes vary in diameter from $\frac{1}{1000}$ to $\frac{1}{2000}$ inch; the collecting tubules progressively

FIG. 54.



A diagram of the sections of uriniferous tubes.

A, cortex limited externally by the capsule; *a*, subcapsular layer not containing Malpighian corpuscles; *a′*, inner stratum of cortex, also without Malpighian capsules; B, boundary layer; C, medullary part next the boundary layer; 1, Bowman's capsule of Malpighian corpuscle; 2, neck of capsule; 3, first convoluted tubule; 4, spiral tubule; 5, descending limb of Henle's loop; 6, the loop proper; 7, thick part of the ascending limb; 8, spiral part of ascending limb; 9, narrow ascending limb in the medullary ray; 10, the zigzag tubule; 11, the second convoluted tubule; 12, the junctional tubule; 13, the collecting tubule of the medullary ray; 14, the collecting tube of the boundary layer; 15, duct of Bellini. (*Kirkes* after *Klein.*)

increase in diameter from $\frac{1}{600}$ to $\frac{1}{200}$ inch. The cells lining the convoluted and intermediate tubules are inclined to the pyramidal shape. Their bases present the appearance of fibers at right angles to the basement membrane (hence "rodded" cells), while their opposite extremities are granular. The tubes of Henle are lined by flattened epithelium for the most part.

The division is somewhat arbitrary, but the *secreting* portion of the tubules is supposed to be confined to the cortical substance, while the tubes of the medullary substance only carry away the fluid.

Blood Supply.—The renal artery, having entered the hilum, divides into branches, two of which usually enter each column of Bertin. Running upward in these columns the branches give off small arterial twigs to the substance of the column. When a point opposite the bases of the Malpighian pyramids is reached each branch follows the convex base of the pyramid to which it is adjacent, the one branch going in an opposite direction to the other. Each meets a corresponding branch from the other side of the pyramid, and thus a convex arterial arch covers the base of the pyramid, from which arch branches go inward to supply the medullary substance and outward to furnish branches to the glomeruli. The arrangement of the vessels in relation to the Malpighian bodies has been noticed. In the glomerulus the capillaries do not form a true anastomosis, but this is not true of the network surrounding the convoluted tubes.

Mechanism of Urinary Secretion.—Histologists have been unable to demonstrate the presence of distinct secretory fibers for the glomerular or tubal cells. This leaves the mechanism of secretion to be explained by (1) the *vascular supply* and by (2) the "vital activity" of the *cells*—both operating in conjunction with osmosis.

Irritation of a certain part of the floor of the fourth ventricle occasions certain marked changes in the quantity and quality of the urine; secretion of the upper dorsal cord temporarily arrests

the secretion; mental emotions, such as fright, anxiety, etc., also modify the flow. All these circumstances, and many others, indicate some control over the activity of the kidneys by the

FIG. 55.

Blood-vessels of the kidney.

A, capillaries of cortex; *B*, of medulla; *a*, interlobular artery; 1, vas afferens; 2, vas efferens; *i*, *e*, vasa recta; *VV*, interlobular vein; *S*, origin of a stellate vein; *i*, *i*, Bowman's capsule and glomerules; *P*, apex of papilla; *C*, capsule of kidney; *e*, vasa recta from lowest vas efferens. (*Stirling*.)

nervous system; but that influence is probably exerted only through *vaso-constrictor* and *vaso-dilator* fibers to the vessels.

Assuming for the present that nearly all the constituents of urine preëxist in the blood and are simply taken out of the circulation in the kidney, it may be stated that, for the most part, the *water* and *salts* are extracted by the cells of the Malpighian bodies, while the *urea* and related *nitrogenous solids* are removed by the cells of the convoluted tubes; so that the specific gravity of the fluid is raised in passing down the tubes. While the histology of the kidney, and especially the arrangement of the glomeruli, is most favorable for the exercise of simple osmosis, and while this process is doubtless mainly responsible for the phenomena which occur, it seems highly probable that the *cells* themselves modify osmotic action by taking an *active part* in the secretion of urine. They undoubtedly exercise a selective affinity accounting for the different materials handled by the glomeruli and the tubes. Moreover, morphological changes in the tubal cells during activity have been microscopically demonstrated. Vesicles are described as forming in the body of the cell, approaching the lumen, bursting and discharging their contents—which are supposed to include the urea and such other materials as may be here extracted from the blood.

As regards the elimination of water and salts by the glomerular epithelium, it must also be admitted that the cells take some obscure but active part. Were this only an osmotic process the amount eliminated would vary exactly as the *pressure*. While usually a rise in renal blood-pressure is accompanied by an increased flow of urine and a fall by a correspondingly decreased flow, the rule does not always hold good. For instance, compression of the renal vein raises the pressure but does not increase the amount of urine.

Another fact, which seems almost if not quite as invariable as the effect of blood-pressure, is that the amount of urine varies directly as the *amount of blood* passing through the kidney, *in-*

dependently of the pressure; and these two facts constitute about all that is definitely known concerning the local conditions affecting the amount of urine. Whether *diuretics* increase the urinary flow by simply drawing water from the tissues into the blood and thus increasing the amount and pressure, or by stimulating the cells of the glomeruli to increased functional activity is a matter as yet undetermined.

Properties and Composition of Urine.—When an ordinary amount of liquid is ingested and when the skin is moderately active the urine, in normal conditions, has a clear reddish amber *color* and a *specific gravity* of about 1020. The more fluid ingested the paler will be the color and the lower the specific gravity; the more active the skin the higher will be the color and specific gravity. The urine is diluted in the first case and concentrated in the second. The fact is, the amount of solids (represented by urea) to be eliminated in 24 hours remains approximately the same, and those solids will cause a high or low specific gravity according as little or much water is eliminated with them. The average *amount* of urine for a day is 2 or 3 pints. Normally it has an *acid reaction* from the presence, not of a free acid, but of acid salts—chiefly acid sodium phosphate. The *odor* is not disagreeable on ejection, but decomposition soon begins and a characteristic offensive, ammoniacal odor develops.

The kidney is the most important excretory organ in the body and the large number of urinary constituents is not surprising. The chief organic constituents are *urea*, *uric acid*, *hippuric acid*, *xanthin*, *hypoxanthin*, *creatinin*, *phenol*, *indican*, *oxalic acid*, *lactates*, etc. The *phosphates*, *nitrates*, *sodium chloride*, and *carbon dioxide* are the chief inorganic materials.

Urea is the most important of the nitrogenous constituents. It contains a large amount of nitrogen. Nearly all of it is removed from the body by the kidneys, and double nephrectomy means death from its retention. Its formation is constant and its removal necessary. Its presence in the blood seems to be the

normal stimulus exciting the activity of the cells of the convoluted tubes.

Whether urea is produced directly in the tissues, or whether only certain substances antecedent to it are there formed, it cannot be doubted that it is the chief final product of nitrogenous ingesta and nitrogenous dissimilation. It is practically the only way in which the nitrogen of proteid foods can escape from the body. It exists not only in the blood but in the lymph, vitreous humor, sweat, milk, saliva, etc. It has been stated that the taking of large quantities of liquids lowers the specific gravity of the urine by diluting it; this is true, but the actual amount of urea is increased somewhat by such a procedure. It is not surprising that the quantity of urea is largely increased when much nitrogenous food is taken, and that it is greatly decreased by an exclusively vegetable diet. Anything, like exercise, which will increase actual tissue metabolism, will increase the output of urea, while anything retarding tissue metabolism, like alcohol, will decrease the output. The average amount of urea for 24 hours is 350 to 450 grains.

Formation of Urea.—Seeing that urea is the typical end product of the physiological oxidation of the proteids, it becomes of interest to determine, if possible, where urea formation takes place. It is known that the *liver* is very active in producing this substance; but it is not alone by this organ that urea is formed. At the present time the prevailing opinion is that, for the most part, the proteids under destructive metabolism in the tissues do not reach the urea stage of transformation, but are converted into *ammonia compounds* (which differ very slightly from the urea in chemical composition), and these compounds are conveyed by the blood to the liver, where the slight change necessary to make them urea is effected under the influence of this organ. *Ammonium carbamate* seems the typical compound, but *ammonium carbonate* and others are probably likewise converted. Artificial circulation of these compounds through the

liver gives rise to urea; removal of the liver increases the ammonia compounds and decreases the urea in the urine; ammonia compounds are normally very much more abundant in the portal blood than in the arterial, but when the liver is removed they are evenly distributed throughout the circulation, and the animal dies in a few days of symptoms which can be aggravated by administration of the ammonia compounds;—all of which circumstances go to show that it is *ammonia compounds* which the tissues produce, and that they are changed to urea in the liver.

Still, removal of the liver does not *suspend entirely* the output of urea. Consequently this substance must be formed elsewhere, but by what organs is unknown. It is not impossible that it is formed to some extent in all organs where proteid dissociation is progressing. This is *practically*, if not really, the case in health at any rate, even under the theory above mentioned.

It is to be noted that urea is not *fully oxidized;* it can be oxidized outside the body. Thus the heat-producing capacity of the proteids is not completely utilized. If they have been broken down in the body into substances simpler than urea, then the amount of heat liberated in such dissociation is consumed in building up the urea molecule to be discharged.

Uric acid is combined in normal urine to form the *urates* of *sodium*, *potassium*, *magnesium*, *calcium* and *ammonium*. The urate of sodium is by far the most abundant of these, and, besides urate of potassium, only traces of the others are found. Free uric acid in human urine is pathological, The urates, like urea, come ultimately from oxidation of the nitrogenous constituents of the body. They are not formed in the kidney, but pass out as such from the blood. About 9–14 gr. are discharged daily. The amount is increased in gout.

In some animals uric acid takes the place of urea, none of the latter being formed. In these cases it is manufactured by the liver from ammonia compounds. This does not, however, seem to be the origin of uric acid in human urine. It has been looked

upon as unconverted urea, *i. e.*, as a product antecedent to urea; but at present such does not seem to be the case. A theory that it is the end product of the destruction of certain materials in the nuclei of cells has considerable support.

Hippuric acid exists in the urine as *hippurates.* It differs from most of the other urinary constituents in being formed in the kidney; it does not preëxist in the blood. The daily output of this substance is about 10 grains, though the amount may be considerably increased on a vegetable diet. The benzoic acid of vegetables seems to be synthesized into hippuric. In proteid dissimilation some benzoic acid may be produced and eliminated in this shape.

The various **lactates** are not formed by the kidney, but pass unchanged into it from the blood. The lactic acid from which they are formed probably results from the transformation of dextrose.

Creatinin is normally present in the urine. It is a nitrogenous body differing from creatin only by a molecule of water. It is eliminated to the extent of about 15 grains per day. A part comes from proteid destruction in the body, and another part is said to come directly, without metabolism, from creatin which is a constituent of ordinary meat. It is not formed in the kidney.

Xanthin, hypoxanthin, etc., are to be regarded as nitrogenous excreta allied to uric acid and resulting in some way from proteid metabolism. They are regarded by some as having the same probable origin as uric acid, viz., the disintegration of cell nuclei.

The non-nitrogenous constituents scarcely deserve separate mention. It is through the kidney that the largest variety and quantity of these materials are discharged. Certain of these are constant, but the wide variety of such materials taken into the alimentary canal accounts for the same wide variety in the urine. The proportion of inert substances in the blood is

approximately constant—kept so by the removal of any excess by the kidneys chiefly.

Sodium chloride is eliminated thus to the extent of about 151 grains daily. The *sulphates* are unimportant. About 25 grains are excreted daily. The *phosphates* are more important, the *acid sodium phosphate* being mainly responsible for the acid reaction of the urine. *Nitrogen* and *carbon dioxide* are the chief gases to be found. The color of urine is due to a substance, *urochrome*, which is probably formed from hemoglobin. Some *mucus* from the bladder is also in the urine.

Variation in Amount and Composition of Urine.—"Its constitution is varying with every different condition of nutrition, with exercise, bodily and mental, with sleep, age, sex, diet, respiratory activity, the quantity of cutaneous exhalation, and indeed with every condition which affects any part of the system. There is no fluid in the body that presents such a variety of constituents as a constant condition, but in which the proportion of these constituents is so variable" (Flint).

Prolonged bodily exercise will increase the amount of urea, but the urine is generally decreased in quantity because perspiration is more active. The *young child* discharges relatively much more urea and urine than the *adult*. The *female* discharges relatively more urine, but less urea, than the *male*. *Digestion* increases the urinary flow. *Climate* and *season* act chiefly though increasing or diminishing cutaneous activity. *Emotions* of various kinds may give rise to an abundant flow of pale urine.

Discharge of Urine.—On leaving the pelvis of the kidney the urine enters the ureters and passes through them to the bladder, whence it is discharged per urethram.

The **ureters** run, one from each kidney, downward and slightly inward behind the peritoneum, a distance of some 18 inches to the base of the bladder. In the female the cervix uteri lies between the two ureters just before they enter the bladder. They penetrate the bladder wall obliquely, their course therein being

nearly an inch long. The effect of this arrangement is that distention of the bladder closes the opening more closely instead of causing regurgitation into the ureter. The ureter is composed of three coats. The outer is fibrous, the middle muscular, and the internal mucous.

The *bladder* serves as a reservoir of the urine until such time as it is convenient for it to be evacuated. This organ, when empty, lies deep in the pelvis in front of the rectum in the male and of the uterus of the female. When moderately distended it will hold about a pint, has an ovoid shape and rises to the brim of the pelvis. It also has three coats. The *outer* is peritoneal, and covers the posterior and small parts of the lateral and anterior surfaces only. Its lower limit posteriorly is the entrance of the ureters. The *middle* layer is muscular. The fibers, which are non-striped, are disposed in three sheets. Their contraction compresses the contents from all directions. Embracing the neck (outlet) of the bladder is a thick band of plain muscle tissue known as the *sphincter vesicæ*. The tonic contraction of this muscle prevents the continual escape of urine. The *inner* coat of the bladder is mucous. It is rather thick, and loosely adherent to the subjacent muscular coat except over the *corpus trigonum* where it is closely attached. The corpus trigonum is a triangular body of fibrous tissue just underneath the mucous membrane; its apex is at the origin of the urethra, and its other angles are at the vesical openings of the ureters.

Absorption from the intact mucous membrane of the bladder takes place very sparingly, if at all. Abrasions of the membrane from any cause allow absorption to occur; and this fact may be made use of to locate lesions giving rise to hematuria. Iodide of potassium injected into the bladder can be detected in the saliva if the bladder is the source of the blood.

Micturition.—When the bladder has become moderately full the desire to expel its contents arises. The act of micturition involves *relaxation of the sphincter vesicæ* and *contraction of the*

muscular walls of the bladder aided by the *abdominal muscles* and *those of the urethra.* A slight contraction of the abdominal muscles compresses the bladder; after a short interval the sphincter relaxes and allows the stream to pass out through the urethra. When the act has been begun contraction of the bladder will suffice to nearly empty the organ, but complete evacuation is finally brought about by a series of convulsive contractions on the part of the muscles of the abdomen.

The **center** controlling the reflex nervous phenomena of micturition is opposite to the fourth lumbar vertebra in the spinal cord.

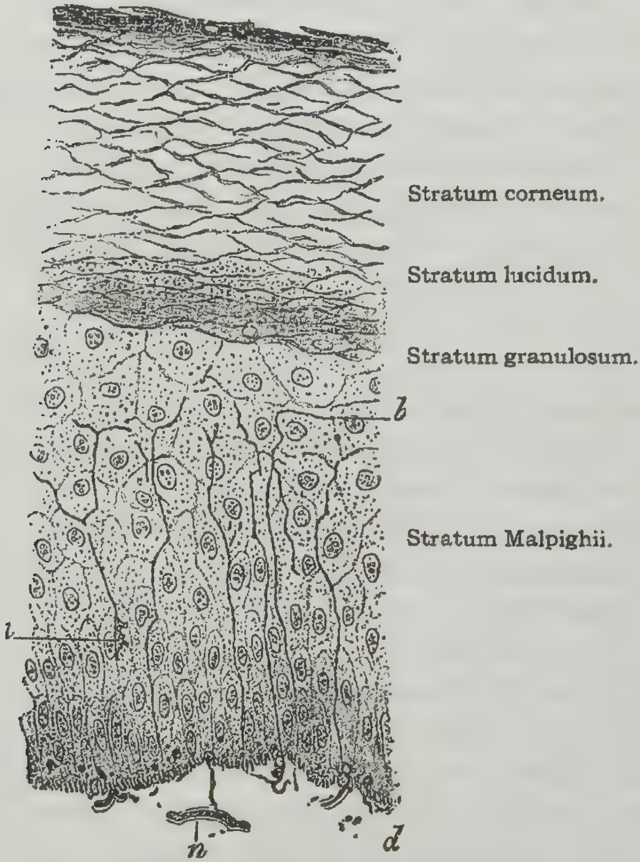
The Skin.

Functions.—The functions of the skin from a physical standpoint are sufficiently apparent. It furnishes protection to the underlying parts, preserves the general contour of the body, affords lodgment for afferent nerve terminations, and thus establishes relations between ourselves and our surroundings. As an organ of excretion it is very important, and in fact essential to life. While various materials, such as urea and CO_2, are thus discharged from the body, their amount is more or less inconsequential, and it appears that it is the action of the skin as a regulator of heat "excretion" which is vital. It furnishes one of the three chief routes for the discharge of water from the body, and it will be seen that it is largely through the output of water that the output of heat is regulated. So necessary is the skin in this respect that the covering with impermeable substances of as much as half the body surface is followed by death.

The skin excretions are contained in the products of the sebaceous and sweat glands. These products correspond altogether to neither the secretions nor the excretions, and the sebaceous glands have been described under the head of secretion. It is to be remembered, however, that the sweat usually represents part of the sebaceous as well as the sudoriparous secretion, because

the mixture of the two is a physical necessity. It is the water of the sweat which is the most important excretion from the skin, although the elimination of CO_2 and inorganic salts, and espec-

FIG. 56.



Vertical section of the human epidermis.
The nerve-fibrils, *n*, *b*, stained with gold chloride. (*Landois.*)

ially of urea in some pathological conditions, is not to be overlooked.

Structure.—The skin consists of an external covering, the *epidermis*, with its modifications, hair and nails, and of the *cutis vera.* Imbedded in the cutis vera are *sebaceous* and *sweat glands* and *hair-follicles.* (Fig. 57.)

Epidermis.—The epidermis consists of at least four layers of epithelial cells. From above downward these are (1) the *stratum corneum*, (2) the *stratum lucidum*, (3) the *stratum granulosum*, (4) the *rete mucosum* or *Malpighii*. All these except the stratum corneum have a fairly constant thickness. The stratum corneum is thick or thin according to location and degree of exposure, and its cells are flat and horny. The lowest cells of the rete mucosum are columnar. From this last-named layer the cells pass gradually upward, and as gradually assume the shape of the horny layer. The horny cells are thrown off and their place is taken by others from beneath. (Fig. 56.)

Hairs are to be found on almost all parts of the cutaneous surface. They consist of a *bulb* and a *shaft*. A depression of the skin involving both epidermis and cutis vera constitutes the *hair-follicle* in which the bulb rests. A projection at the bottom of the follicle corresponds to a papilla, and upon it the bulb is placed. The shaft has an oval shape in cross section. It is composed of fibrous tissue, outside which is a layer of imbricated cells.

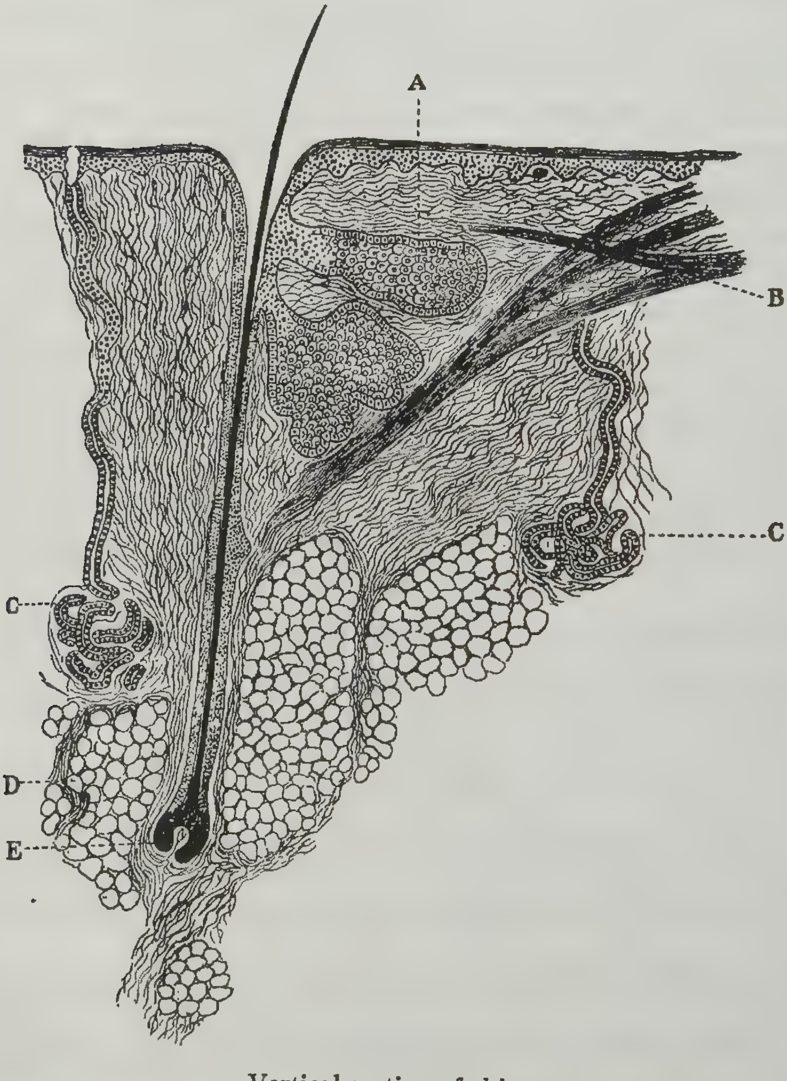
Nails consist of a superficial layer of horny cells and a deeper one corresponding to the rete mucosum. The root of the nail is received into the matrix—a specialized portion of the cutis vera.

Cutis Vera.—The cutis vera is tough but elastic. It rests upon cellular and adipose tissue. Its structure is areolar with some non-striated muscle fibers. Projecting from the cutis vera into the epidermis are minute conical elevations, the *papillæ*. Many of them contain sensory nerve terminals.

Sweat Glands.—Practically the whole cutaneous surface contains sweat glands. Some two and a half millions are thought to exist in the skin of the average individual. They are particularly abundant in the skin of the palms of the hands and soles of the feet. They belong to the simple tubular type, and consist of a secreting portion and an excretory duct. The secreting part lies

just underneath the true skin and, as a whole, resembles a small nodule; however, the nodule consists of an intricate coiling of the tube itself which is of tolerably uniform diameter throughout.

FIG. 57.



Vertical section of skin.

A, sebaceous gland opening into hair-follicle; B, muscular fibers; C, sudoriferous or sweat-gland; D, subcutaneous fat; E, fundus of hair-follicle, with hair-papilla. (*Kirkes* after *Klein.*)

It curls upon itself some 6–12 times and ends by a blind extremity. It is lined by epithelial cells.

The duct passes away from the glandular coil, runs through the cutis vera in a comparatively straight course and assumes a spiral shape as it traverses the epidermis to open obliquely on the surface. With the ducts of the larger glands are connected a few non-striped muscular fibers which may aid in the discharge of the secretion. (Fig. 57.)

Properties and Composition of Sweat.—The secretion is colorless, has a slight characteristic odor, and a salty taste. Its specific gravity is about 1003–4, and its reaction is usually acid when just discharged. It contains a large proportion of *water*, a little *urea* and *fatty matter*, and quite a quantity of inorganic salts of which the chief is *sodium chloride*. All the constituents in health are of subsidiary importance except the water. Under average conditions of temperature and exercise the amount secreted in 24 hours is about 2 pounds. But the quantity is very variable—as much so as the urine, and may be said in a general way to vary inversely as the urinary secretion.

Mechanism of the Secretion of Sweat.—Sweat is produced continuously, though up to a certain point it passes off as vapor or "insensible perspiration." Beyond that point it accumulates on the skin as an evident fluid and becomes "sensible perspiration." Whether it escapes as sensible or insensible perspiration, it is secreted as a *fluid*.

The activity of the cells lining the glandular coils in separating sweat from the blood is undoubted. Distinct secretory fibers are distributed to them, and through the influence of these fibers the glands will secrete sweat even without an increase in the blood supply. But usually a determination of blood to the surface means an increase of perspiration. This occurs during violent exercise, *e. g.* However, that the production of sweat is not altogether dependent on this factor is shown by profound sweating in shock, nausea and like conditions when the skin is pale

and cold, and by dryness of the flushed skin in febrile diseases. Furthermore, experiments on inferior animals have revealed fibers which influence the secretion of sweat without affecting the blood flow.

Practically, in health, the only conditions which increase the flow of perspiration are muscular exercise and a high external temperature. Of these, exercise probably works through the nerve centers; external heat does not stimulate the glands directly, but irritates the cutaneous terminations of afferent fibers which convey impressions to the sweat centers, whence messages are sent out by secretory fibers to the glandular epithelium and their activity begins. In both cases there is accompanying dilatation of the superficial vessels under the influence of the vaso-dilator fibers.

It is supposed that the chief **center** is in the medulla oblongata and that secondary centers exist in the lumbar region of the cord.

The amount of CO_2 eliminated by the skin is inconsiderable in the human being.

CHAPTER X.

THE NERVOUS SYSTEM.

General Functions of the System as a Whole.—The nervous system is the most delicately organized part of the animal body. Its sensory terminations receive impressions which are conducted to the centers; it conveys impulses from the centers to the different parts of the body, controlling and regulating their action. Connecting, as it does, all parts of the organism into a coördinate whole, it is the only medium through which impressions are received, and is the only agency through which are regulated movement, secretion, calorification and all the processes of organic life. This system, ramified throughout the body, connected with and passing between its various organs, serves them as a bond of union with each other, as well as with the brain. The mind influences the corporeal organs through the instrumentality of this system, as when volition calls them into action; on the other hand, changes in the organs of the body may affect the mind through the same channel, as when, for instance, pain is mentally perceived when the finger is burned. Thus it is that the nervous system becomes the main agent in what is known as the "life of relation;" for without some medium for the transmission of its mandates, or some means of receiving those impressions which external objects are capable of exciting, the mind would be completely isolated, and could hold no communion with the external world.

It should not be understood, however, that the nervous system cannot operate independently of mental influence. All those manifestations of nervous activity connected with the perform-

ance of the so-called "organic functions" of life as digestion, circulation, etc., are not directly influenced by volition; indeed an essential character of these functions is that they are completely removed from the influence of the will; to be conscious subjectively of their performance is an evidence of abnormality.

The first step in every voluntary act is a mental change, in which the act of volition consists. If this mental change be of such nature as to direct its influence upon a muscle, or a particular set of muscles, the contraction of those muscles immediately supervenes, so as to bring about the predetermined voluntary act. But the influence of the will could not possibly be exerted upon those muscles except through intervention of the nerves.

Furthermore, a certain mental state, in cases of common or special sensation, is induced by an impression made upon certain bodily organs. But in no case could the mental state be produced unless a particular part of the nervous system were present to convey the impression received to the center capable of recognizing it. If the hand be burned pain is felt, but were the nerves not present to convey the impression made by the heat no degree of temperature could make the mind cognizant of injury. When light is admitted to the eye a corresponding mental sensation is produced, but for the production of this the integrity of the optic nerve is a necessary condition.

It will be gathered from the foregoing remarks that the nervous system is not only capable of conveying communications, but that it has the power, in certain of its divisions, of receiving impressions and of giving rise to stimulating influences—that is, that it is capable of generating a peculiar power known as "*nerve force.*" It thus becomes the seat of distribution of energy to all the cells. These generating parts of the system are the reservoirs of force—force which has been derived from the cells and is distributed to them. This nervous force, having its origin in the living activity of the cells, is the highest manifestation of vital energy.

The nervous structure is divided into two great *systems:*

1. The **Cerebro-Spinal System** consists of the brain, the spinal cord and all the nerves which run off from these. This system is especially concerned with the functions of *relation*, or of *animal life*. It presides over general and special sensation, over voluntary movements, over intellection, over all conscious activity, and over all other functions which are peculiar to the animal. It is by this system that we know of and deal with the other great system. It is also called the Animal, or Inorganic, System.

2. The **Sympathetic, Organic, Ganglionic or Vegetative System** is especially connected with the functions relating to *nutrition*—functions similar to those occurring in the vegetable kingdom. It presides over all organic life—over all unconscious activity. While the operations over which this system holds sway are quite different from those under the supervision of the cerebro-spinal system, it must not be concluded that the two are not anatomically and physiologically related. Neither is independent of the other, as was once thought, but both are parts of the same great apparatus.

Divisions of the Nervous Substance as a Whole.—The nervous matter, irrespective of the two systems, may be studied as consisting of two divisions. The first is made up of **cells;** the second of tubes, or **fibers.** Although the tissue may be thus divided into nerve cells and nerve fibers, the present conception of the arrangement of the nervous substance is that these two are only different parts of the same element known as the **neuron,** supported by tissue elements known as *neuroglia*, which, though not identical with connective tissue, is comparable to it in its function of support. The neuron, thus considered, consists of a protoplasmic body which sends out a number of branching processes called *dendrites*, one of which becomes the *axis cylinder*. While, therefore it is to be understood that the cell and the fiber in the nervous system are both portions of an identical whole, a

description of them as separate parts is warranted for the sake of convenience and by differences in their general characteristics.

The nerve cells are the only organs capable, under any circumstances, of *generating nerve force.* As a rule they are stimulated to generate this force by the reception of an impression through the nerve fiber, but they may in some cases be directly excited by mechanical, electrical or chemical means. They also frequently act as *conductors*, as will be seen later.

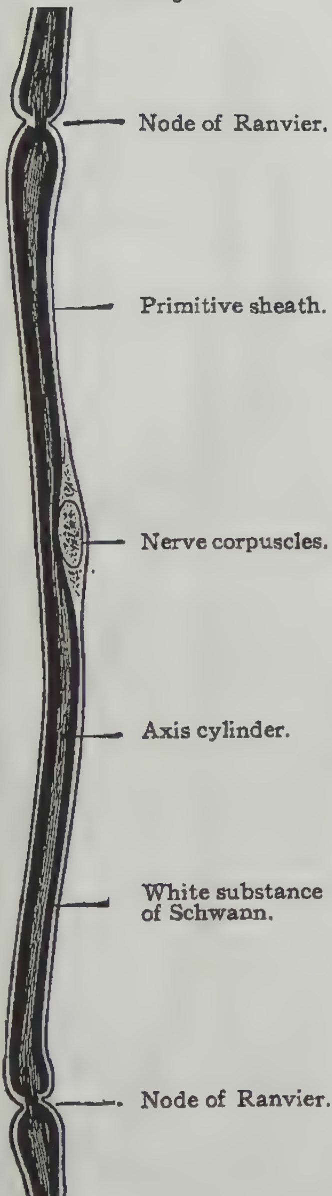
Under no circumstances can nerve fibers generate force. Their office is exclusively to *conduct* impressions and impulses, and they usually receive these impressions and impulses at their terminal extremities in the case of afferent nerves, and from the centers in the case of efferent nerves; but in many instances they may be stimulated in any part of their course. Some fibers are incapable of being thus directly stimulated. The nerves of special sense are insensible to direct stimulation.

Nerve Fibers.—Nerve fibers are of two kinds: (*A*) *white* or *medullated* fibers and (*B*) *gray* or *non-medullated* fibers. The non-medullated fibers possess the conducting elements alone, while the medullated possess certain accessory anatomical elements.

(*A*) Each **medullated fiber** has (1) an external enveloping membrane called the *neurilemma*, or the *primitive nerve sheath*, or the *sheath of Schwann;* (2) an intermediate substance known as the *myeline sheath*, or the *white substance of Schwann*, or the *medullary substance;* (3) a central fiber, the true conducting element, which usually goes under the name of the *axis cylinder*, or *axione.*

The *sheath of Schwann* is analogous to the sarcolemma of muscle fibers. It is a structureless protective membrane, somewhat elastic, and presents oval nuclei with their long diameter corresponding to the direction of the fiber. This sheath is wanting over the medullated fibers in the white substance of the brain and spinal cord.

FIG. 58.



Scheme of a medullated nerve fiber of a rabbit acted on by osmic acid.
The incisures are omitted. × 400. (*Landois.*)

It is the *white substance of Schwann* which gives to the nerve its peculiar whitish appearance. This is a fatty substance of a semi-fluid consistence. It fills the tube made by the sheath of Schwann and surrounds the axis cylinder. It is wanting at the origin of the fibers in the centers and at their peripheral distribution. It is probably not necessary to conductivity. In fresh nerves this substance is strongly refractive, and the optical effect produced by its varying thickness in the center and at the edges is the appearance of dark borders. It easily coagulates into an opaque mass. The idea that the myeline sheath acts as an insulator lacks supporting evidence. The theory that it is nutritional is plausible; but no sufficient difference in the medullated and non-medullated fibers in this respect has been found to establish the theory as a fact. At certain points in the course of medullated fibers there are seen constrictions called the *nodes of Ranvier*. At these points the medullary substance is wanting and the sheath of Schwann is in contact with the axis cylinder. It is not improbable that these nodes furnish a mode of access for the nutrient plasma. Certain it is that they are most numerous where physiological activity is supposed to be most active.

The *axis cylinder* is composed of a large number of primitive fibrillæ. This band occupies about one-fourth the diameter of the tube and is the true conducting element, as is shown by its invariable presence, its continuity and other considerations equally conclusive. It is demonstrated under the microscope with difficulty in fresh specimens. It is directly connected with a nerve cell, and is the essential part of the fiber. The process of the cell which becomes the axis cylinder is not, as was once thought, unbranched, but itself sends off "collaterals" in the gray substance. These collaterals, however, do not actually join any other nerve cells or fiber.

FIG. 59.

Non-medullated nerve fiber.

Vagus of dog. *b*, fibrils; *u*, nucleus; *p*, protoplasm surrounding it. (*Stirling*.)

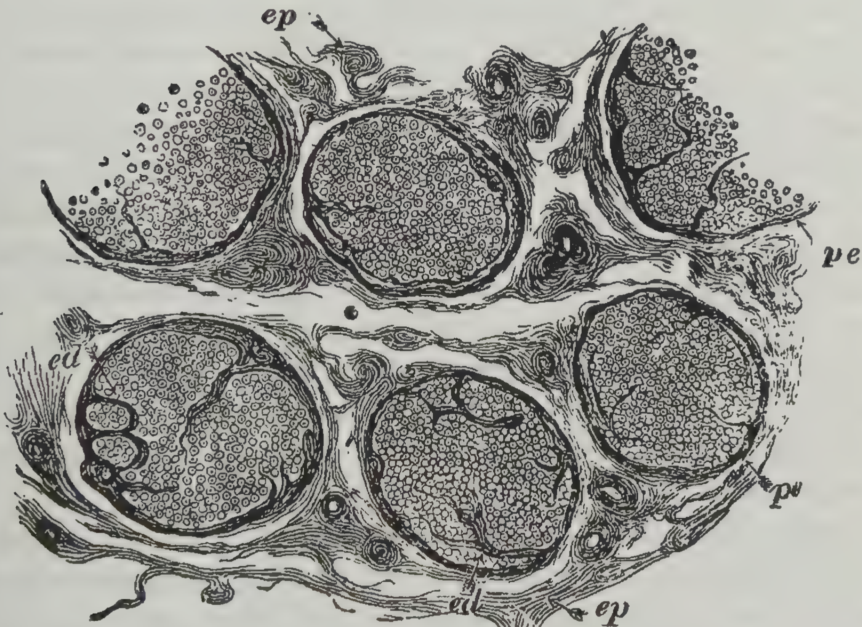
The average diameter of medullated fibers is about $\frac{1}{2000}$ in., though all are said not to preserve the same diameter throughout their course.

(*B*) **The non-medullated fibers** (fibers of Remak) seem to be simple axis cylinders without the other anatomical elements peculiar to medullated fibers. They make up a large part of the trunks and branches of the sympathetic system, and represent the filaments of origin and distribution of all nerves. They are thought by some to possess a neurilemma. They are pale gray in color.

Nerve Trunks.—The above remarks apply to a single nerve fiber. These

fibers seldom run an extended course alone, but are bound together in large numbers to make a nerve trunk. This trunk is composed of a number of bundles of fibers, and is surrounded by a connective tissue membrane known as the *epineurium;* the separate bundles, or funiculi, are surrounded each by a similar membrane called the *perineurium;* while inside the funiculi, between the primitive fasciculi, is a delicate supporting

FIG. 60.



Transverse section of a nerve. (Median.)
ep, epineurium; *pe*, perineurium; *ed*, endoneurium. (*Landois.*)

tissue known as the *endoneurium*, or the *sheath of Henle.* In connection with this sheath there are nuclei belonging to the connective tissue and to the nerve fibers themselves. The sheath begins where the nerve fibers emerge from the white portion of the centers, is interrupted by the ganglia in the course of the fibers, branches as the bundle branches, and is lost before the terminal distribution is reached. It is seldom found surrounding single fibers. It is likewise rare for capillaries to penetrate it and reach

the fibers themselves. There are numerous lymph spaces around the individual fibers as well as around the funiculi. In situations where the nerves are well protected, as in the cranium, the amount of fibrous tissue in the trunks is small, but where opposite conditions prevail, as in muscular substance, this tissue is largely increased in amount as regards both that which surrounds the trunk and that which is sent in between the funiculi and fibers. This tissue has ramifying in it a network of fibers known as nervi nervorum. The blood supply is not large.

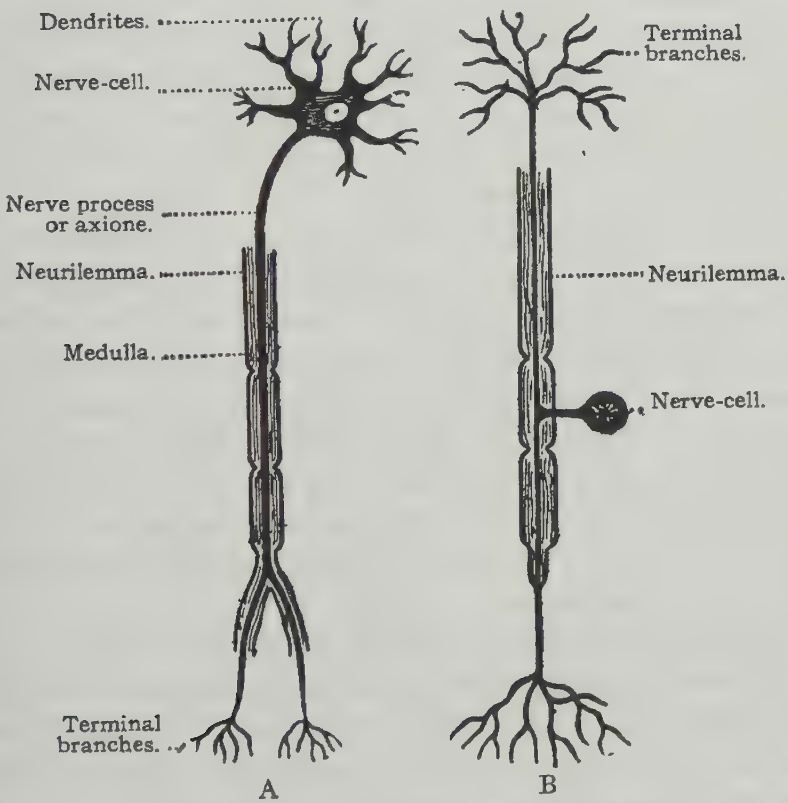
Individuality of Nerve Fibers.—It is to be remembered that so far as can be determined every nerve fiber, having entered a trunk, proceeds without interruption to the part to which it is finally distributed, whether that part be the skin, or a viscus, or a muscle, or a gland, or some organ of special sense, or another nerve cell, or what not. Collections of fibers forming bundles run together in the same trunk, may leave that trunk together, may send out part of their fibers to another bundle or trunk, or may receive other fibers from other funiculi; but everywhere the relation of the primitive fibers to each other is simply one of contiguity. However, as the axis cylinder approaches the seat of its final distribution, it breaks up into several fibrillæ, such divisions always taking place at the nodes of Ranvier.

Nerve Centers.—The nerve centers include the gray matter of the brain and cord and the ganglia in both the cerebro-spinal and sympathetic systems. These centers have a gray color due to the presence of a pigmentary substance in the cells and surrounding tissue. The ganglionic centers are simple collections of nerve cells with their usual accessory elements—myelocytes, intercellular granular matter, delicate membranes covering some of the cells, connective tissue elements, blood-vessels and lymphatics.

Nerve Cells.—These are irregular in shape and may be unipolar, bipolar or multipolar. They also vary much in size. The *unipolar* cell has a single prolongation which becomes the axis

cylinder. *Bipolar* cells are prolonged in two directions, and may be looked upon as simply protoplasmic enlargements of the nerve fiber. This cell is frequently covered by a connective tissue envelope which is continuous in both directions with the sheath of Schwann. *Multipolar* cells have three or more prolongations,

FIG. 61.



A, efferent neuron; B, afferent neuron. (*Brubaker.*)

one of which always becomes continuous with the axis cylinder and is called the *axis-cylinder process*, the *neuraxon*, or the *axione*. The other poles branch in various irregular directions like the limbs of a tree, and are hence called *dendrites*. They also go under the name of *protoplasmic prolongations*. Some of these unite the cells to contiguous cells by interlacing with, but not

actually joining, similar poles from those cells. The multipolar cells in the anterior cornua of gray matter of the cord are said to be larger in size and to present more poles than corresponding cells in the posterior column.

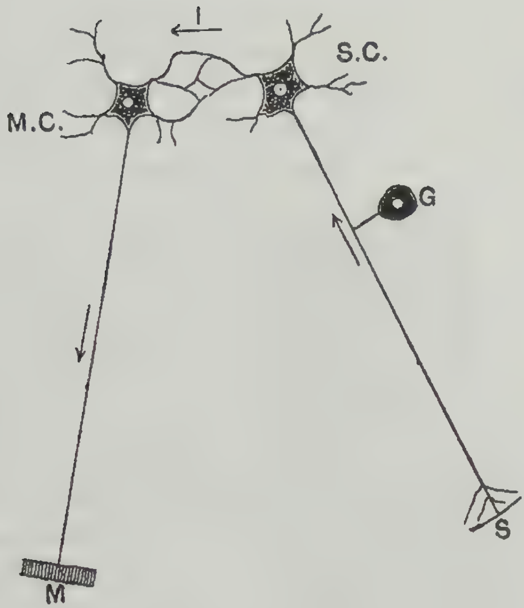
The diameter of nerve cells varies from $\frac{1}{1250}$ to $\frac{1}{500}$ in. The nucleus is usually single, and most cells have no true surrounding membrane. If a nerve fiber be followed toward the center which gives it origin it will be found first to lose its sheath and later its medullary substance; this medullary substance may continue for some distance after the sheath is lost, as in the white substance of the encephalon, but never penetrates the gray substance proper. Every nerve fiber is connected with a cell by that cell's axis-cylinder prolongation.

Certain retrograde changes take place in the neurons in old age—morphological changes agreeing with the physiological decrease in energy-producing power at that time. The cell body becomes smaller, the dendrites atrophy, and the axiones diminish in mass. Nerve "fatigue" can also be demonstrated by the microscope. The nuclei of the sheath are flattened, the protoplasm is shrunken and vacuolated and the nucleus is crenated. The quantity and quality of the food may be perfect, but the power of the cell to utilize it is impaired, and this means diminished physiological power.

Communication Between Different Neurons.—*Every neuron is anatomically independent of every other neuron.* There is no actual joining of fibers or dendrites—simply an interlacement of the end arborizations. This is illustrated in Figs. 62 and 63. In the latter the afferent fiber is joined to no cell except G, one of the cells of the spinal root ganglion. Its end arborizations simply interlace with the dendrites of the motor cell M. C. and cause it to send out an efferent impulse to the muscle M.

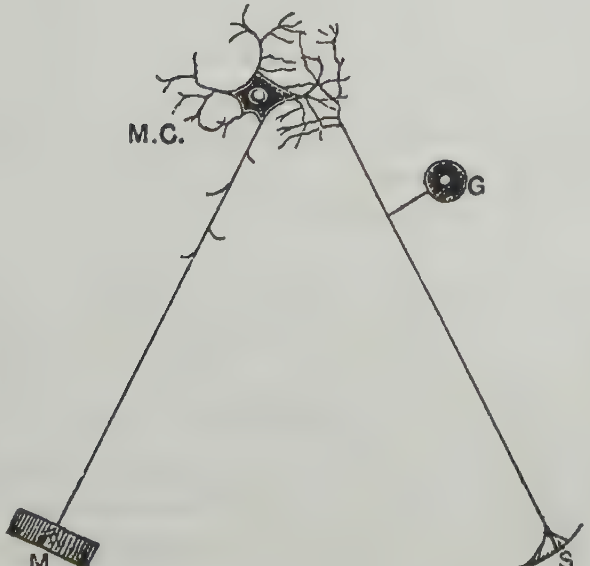
Furthermore, there are frequent relays in the transmission of nerve messages. By no means do all the fibers from the motor area of the brain pass *themselves* out as parts of the anterior roots.

FIG. 62.



Reflex action: old idea. (*Kirkes.*)

FIG. 63.



Reflex action: modern idea. (*Kirkes.*)

FIG. 64.

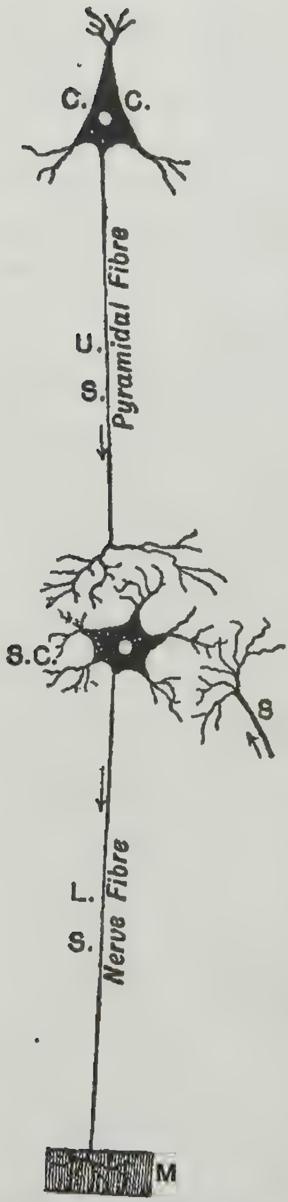


Diagram of an element of the motor path.

U.S, upper segment; L. S, lower segment; C.C, cell of cerebral cortex; S.C, cell of spinal cord, in anterior cornu; M, the muscle; S, path from sensory nerve roots. (*Kirkes* after *Gowers*.)

The relay service is illustrated in Fig. 64. Here again, it is seen that there is no actual joining of the neurons. Whenever it is said that a nerve cell is "joined" to another, or that the axis cylinder of a cell "joins" another cell, no actual continuity of tissue is meant. Different neurons communicate only by contiguity.

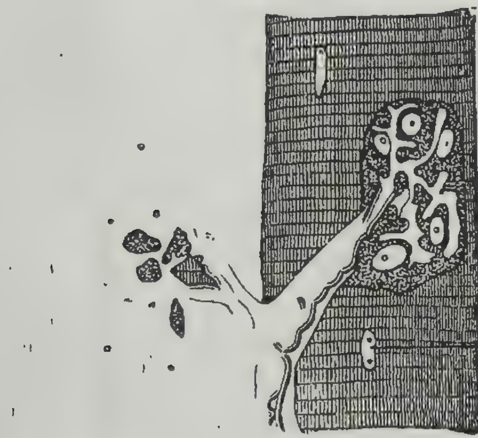
Peripheral Nerve Terminations.—Nerves terminate peripherally (1) in *muscles*, (2) in *glands*, (3) in *special organs* connected with the senses of sight, hearing, smell and taste, (4) in *hair-follicles*, (5) in simple *free extremities* passing between epithelial and other cells, and (6) in several kinds of so-called *tactile corpuscles*.

The motor nerves passing to **voluntary muscles** form first a "ground plexus" for each group of muscle bundles—this plexus being made of the axis-cylinder fibrillæ. From this plexus fibrils pass to form an "intermediary plexus" corresponding to each muscle bundle. These fibrils are still medullated, and when a branch from the intermediary plexus enters a muscle fiber its sheath becomes continuous with the sarcolemma of that fiber, and the axis-cylinder fibrils form a network on the surface of the muscle fiber. This is called an *end motorial plate*. It contains a number of nuclei, and sends off from its under surface fine fibrillæ which are said to pass between the muscular fibrillæ which make

up the fiber. Sensory fibers are somewhat scantily distributed to the voluntary muscles.

In **plain muscle** tissue the motor nerves are distributed after the same general manner as in the striped muscles, though with some differences. Here the fibers are not medullated, and

Fig. 65.



Termination of a nerve fiber in end-plate of a lizard's muscle. (*Stirling.*)

primitive fibrils passing from the intermediary plexus finally enter the nuclei of the muscle cells.

Medullated fibers have been traced to the cells of **glands,** but not farther. It is thought by some that, having formed a plexus, non-medullated fibers pass in to terminate in the nucleoli of the gland cells, though such endings have not been demonstrated.

The peripheral distribution of nerves connected with the **special senses** will be discussed elsewhere.

The remaining methods of termination above noted apply to afferent nerves. It is claimed that a very large number of sensory nerves terminate in **hair-follicles.** If such be the case it will account for sensory terminations in by far the greater part of the cutaneous surface. It is supposed that nerve fibrillæ form a plexus beneath the true skin and send branches thence to the

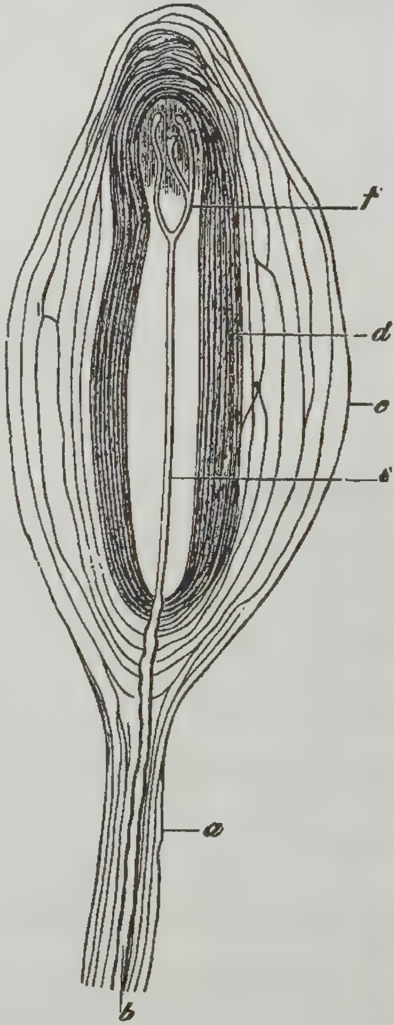
follicles, though the exact mode of termination is a question of some obscurity.

Terminations between **epithelial cells** are probably more common than any other method of sensory distribution. The fibers, having passed to the surface of the skin or mucous membrane, lose everything excepting the axis cylinder, which, dividing into minute ramifications, passes, by means of these fibrillæ, among the epithelial cells. This mode of termination is held by some to prevail in the glands. It certainly prevails in parts other than the skin and mucous membranes.

Sensory nerves further terminate in (*a*) the *corpuscles of Pacini* or *Vater*, (*b*) the *end bulbs*, or *tactile corpuscles, of Krause*, (*c*) the *tactile corpuscles of Meissner*, (*d*) the *tactile menisques*, and (*e*) the *corpuscles of Golgi*.

(*a*) The **Pacinian corpuscles** are oval elongated bodies. Each corpuscular body has a length of about $\frac{1}{12}$ of an inch, and is about half as broad. It is made up of a number of concentric layers of connective tissue in a hyaline ground substance, and is attached by a pedicle to the nerve whose termination it is. Through this pedicle passes a single (occasionally more) nerve fiber which,

FIG. 66.

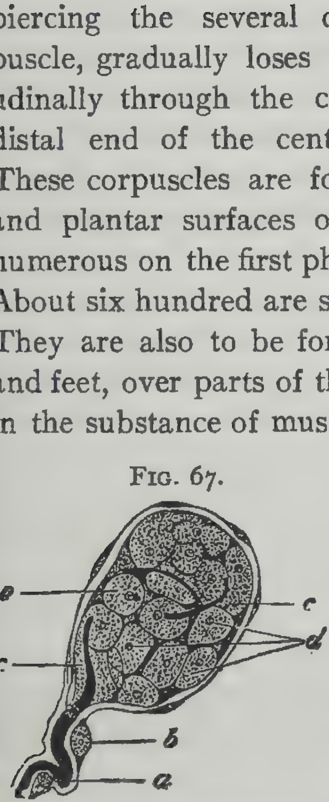


Vater's or Pacini's corpuscle.

a, stalk; *b*, nerve fiber entering it; *c*, *d*, connective-tissue envelope; *e*, axis-cylinder with its end divided at *f*. (*Landois*.)

piercing the several concentric layers constituting the corpuscle, gradually loses its myeline substance and runs longitudinally through the center of the body to terminate at the distal end of the central cavity in a knob-like enlargement. These corpuscles are found in great abundance on the palmar and plantar surfaces of the hands and feet, being far more numerous on the first phalanx of the index finger than elsewhere. About six hundred are said to be present in each hand and foot. They are also to be found on the dorsal surfaces of the hands and feet, over parts of the forearm, arm and neck, in the nipples, in the substance of muscles, in all the great plexuses of the sympathetic system, and in numerous other situations. These bodies cannot be considered true tactile corpuscles because they are situated beneath the skin; neither can they be positively said to have any "special sensory" function such as the appreciation of temperature, weight, etc.

FIG. 67.



End bulb from human conjunctiva, treated with osmic acid, showing cells of core. (From *Yeo* after *Longworth.*)

a nerve fiber; *b*, nucleus of sheath; *c*, nerve fiber within core; *d*, cells of core.

(*b*) The **end bulbs of Krause** exist in great number in the conjunctiva, the glans penis and clitoris, the lips, and in other situations. They bear some resemblance to the corpuscles of Pacini, but are much less elaborate in their arrangement; the number of concentric layers is much smaller, while the contained mass is larger. The shape is spherical. From one to three medullated fibers pass from the underlying plexus to wind through the corpuscle and break up in free extremities. The sheath of the fiber is continuous with the outer covering of the corpuscle, and the medulla, is gradually lost as the fiber enters the bulb. The end bulb of Krause measures from $\frac{1}{1000}$ to $\frac{1}{250}$ of an inch in diameter.

(*c*) The tactile **corpuscles of Meissner** have to do with the sense of touch, and are situated largely in the papillæ of the skin covering the palmar surfaces of the hands and the plantar surfaces of the feet; they also exist in other situations, corresponding in general to the distribution of the Pacinian corpuscles. The largest number is found over the distal phalanges of the fingers and toes on their palmar and plantar surfaces; they diminsh in

FIG. 68.

Drawing from a section of injected skin.

Showing three papillæ, the central one containing a tactile corpuscle, *a*, which is connected with a medullated nerve, and those at each side are occupied by vessels. (From *Yeo* after *Cadiat.*)

number proximally from these points. They may be simple or compound according as the enclosing capsule contains one or more collections of nucleated cells. Their form is oblong with the long axis in the direction of the papilla. They vary in thickness with the papillæ of the region in which they are located. They may have a transverse diameter of from $\frac{1}{500}$ to $\frac{1}{150}$ of an inch, and probably in most instances occupy the secondary eminences of the papillæ in which they are found. A simple papilla does not generally possess both vascular and nervous loops.

(*d*) The **tactile menisques** are found in certain cutaneous regions. Nerves in the superficial layer of the skin lose their medullary substance and divide to form arborizations which are flattened into the form of a leaf.

(*e*) The **corpuscles of Golgi** are situated at the point of union of tendons with muscles, and are believed by some to have to do with the muscular sense. They are flattened fusiform bodies composed of granular substance enclosed in layers of hyaline membrane and containing nervous fibrillæ.

Properties and Classification of Nerve Fibers.—Nerve fibers are for the purpose of *conveying* messages either peripherally or centrally. They may be stimulated to action by anything capable of suddenly increasing their irritability. In any case the effect of the stimulus, whether normal or abnormal, is manifested at the *peripheral distribution* of the stimulated fiber. So far as most external manifestations are concerned, nerves may be classified as **motor** and **sensory.** That is to say, stimulation, for instance, of a cerebro-spinal nerve (except those of special sense) is followed, under ordinary conditions, by one of two results—there is either pain or contraction of a muscle to which the nerve is distributed. This is a typical illustration of the action of motor and sensory fibers, and the manifestation of nerve action, whether it consists in pain or motion, is a result only of the conduction of an impression of an impulse to the center or the periphery. It is to be noted that the result of thus stimulating a nerve fiber is manifested at *one* extremity only of that fiber, and always at the *same* extremity.

However, since there are nerve fibers the stimulation of which is not followed by pain or motion, the division into sensory and motor fibers is not comprehensive enough to include all the fibers in the body. But since, as above stated, the only office of fibers is to conduct, and since they always conduct in a direction either *toward* or *away from* the center, all nerves may be classified as either **centripetal** or **centrifugal.** A corresponding division is into **afferent** and **efferent.** It will be seen that all motor fibers are centrifugal or efferent, but not all centrifugal or efferent fibers are motor. It will likewise be seen that all sensory fibers are centripetal or afferent, but not all centripetal or afferent fibers

are sensory. For impressions made upon the terminations, or upon the trunk, of a centripetal nerve may cause (1) *pain*, or some other kind of sensation; (2) *special sensation*, (3) *reflex action* of any kind; (4) *inhibition.* Similarly impressions made upon a centrifugal nerve may (1) cause *contraction of a muscle* (motor nerve); (2) *influence nutrition* (trophic nerve); (3) *control secretion* (secretory nerve); (4) *inhibit, augment,* or *stop* any other efferent action (Kirkes).

To these two classes, efferent and afferent, should be added a third, the **intercentral** fibers which connect different parts of the nervous centers. Most of these even can be called either afferent or efferent.

Characteristics of Efferent Nerves.—In case of these nerves a force is generated in the centers and conveyed by the nerves to the periphery, where it manifests itself in one of the ways mentioned above as characteristic of centrifugal fibers. Division of these fibers, or interference with their conductivity by disease or otherwise, renders impossible the manifestation of nervous force generated in the center, for the simple reason that the organ to which the fibers are distributed cannot receive the message intended for it. For instance, a muscle cannot, by the most persistent effort of the will be made to contract if the motor fibers running to that muscle are divided. In case, however, of division of efferent nerves, if the peripheral end be irritated, thus roughly counterfeiting normal stimulation, the ordinary effects of normal stimulation will be brought about, provided (as is usually the case) that particular nerve can be thus directly stimulated. Stimulation, however, of the central end of such a cut nerve produces no effect. No matter whether such efferent nerves receive their stimulus directly from the center or artificially, as by mechanical or electrical means, the effect is produced in the *end organs*, whatever they may be. It is an invariable law to which reference has already been made, that a nerve fiber thus conducting a message in either direction is not inter-

fered with by the proximity of other fibers, similar or dissimilar. Such message is not in any way imparted to a neighboring fiber or diffused through the fasciculus, but is conveyed uninterruptedly to its destination. It is possible that the myeline sheath has an insulating effect upon the contained axis cylinder, just as an electric wire may be insulated by non-conducting substances like silk, but this is doubtful.

Interesting manifestations of motor centrifugal impulses are seen in certain movements associated with corresponding muscles on different sides of the body and with sets of muscles on the same side. It is almost impossible to effect certain movements with a single finger or toe without causing similar movements in other fingers and toes; a part of a muscle cannot be made to contract separately; it is doubtful if it be possible to move one eye-ball without the other, even by the most persistent practice. Other similar examples are numerous. It is quite probable that in most cases these associated movements are solely matters of habit. But the connection by commissural fibers of the cells in the centers controlling and regulating the movement of these muscles and sets of muscles would offer a not unreasonable explanation of the phenomena in question, since such an arrangement might render impossible separate and individual action by the cells thus connected. Excepting, perhaps, the movements of the eye-balls, these associated movements can be greatly modified by education.

Characteristics of Afferent Nerves.—Impressions received by these fibers, although they are conveyed toward the center and must reach a center before there is any nervous manifestation, are always *referred* to the periphery. A most common illustration of this fact is furnished by injury to the ulnar nerve as it passes the elbow—such injury being manifested not usually by any pain at the point of infliction, but on the ulnar side of the hand where the nerve is distributed. A person whose limb has been amputated often seems to feel pain in the extremity although it has

been removed from the body—such pain coming from compression by the cicatrix (or otherwise) of the nerves which before the amputation were distributed to the severed limb. Here, as in the case of efferent nerves, division of the fibers between the seat of impression and the center precludes the possibility of any nervous manifestation. That is to say, no pain will be felt, no matter how great the injury be, if the sensory fibers running from the seat of injury be divided. Stimulation of the peripheral end of a divided afferent fiber produces no effect; but stimulation of the central end is followed by the ordinary manifestation —by pain if the nerve stimulated be a common sensory one. This remark, of course, applies only to those nerves which can be thus directly stimulated—typically to true sensory fibers.

Impressions conveyed by nerves of special sense must be received through the intervention of certain complex organs, consideration of which belongs elsewhere.

Although a division has been made of nerve fibers into afferent and efferent, each with definite, proper and dissimilar functions so far as the direction of conduction is concerned, it has been impossible to discover any actual difference in the composition, appearance, or other properties, of the actual fibers themselves. In fact, it may be even considered as only an accident that one fiber conveys a message peripherally and another centrally—an accident dependent upon the kind of center which with the fiber is connected and the kind of termination it has in the periphery.

Direction of the Current in Nerve Fibers.—It has long been understood that in no case will a fiber *in situ* convey a message at one time in one direction and at another in an opposite one, that no individual fiber can be both afferent and efferent; and so far as *practical* action is concerned this is true, but "experiment has shown that if a nerve trunk be stimulated at a given point, then the nerve impulse can be demonstrated as passing away from the point of stimulation in *both* directions" (American Text-book). However, only the message traveling in the physiological direc-

tion is manifest, for it is the only one which finds a suitable *terminal.*

It is not to be concluded, however, that in any nerve trunk, as the ulnar nerve, there may not be both afferent and efferent fibers. Such, in fact, is the usual arrangement. Any nerve trunk may contain all kinds of fibers—sensory, special sensory, vaso-motor, motor, trophic, secretory—but the presence of all these does not interfere with the individuality and the individual action of each fiber. A nerve trunk containing more than one kind of fibers is called a *mixed nerve.*

Speed of Nervous Conduction.—It is stated that *afferent* impressions are conveyed by nerves at the rate of about 120 feet per second; the rate for *efferent* impulses is somewhat less rapid, probably 110 feet. *In the spinal cord* tactile impressions are conveyed a little faster than in the nerves proper, and painful impressions somewhat less than one-half as fast. The rate of motor conduction in the cord is said to be one-third the rate in the nerves. It has also been demonstrated that an *act of volition* requires a definite time for the *inception of its performance;* this is stated to be about $\frac{1}{28}$ of a second. The *recognition* of a *simple impression* (conveyed in the opposite direction, of course) requires about $\frac{1}{25}$ of a second. Furthermore, the part played by the spinal cord in *reflex action* (to be considered later) also consumes an appreciable period; this is found to be more than twelve times the period occupied in the transmission of the impression to the cord or the impulse back to the muscles.

Action of Electricity Upon Nerves.—A nerve may be irritated in any one of several ways; but mechanical, thermal and chemical irritants, besides working injury to the tissues, are much less easily managed and regulated than is electricity. This agent may be applied time after time to a nerve trunk without causing any permanent change in its conductivity, and the strength, time and duration of application, etc., can be accurately governed.

It has been noticed that the uninterrupted flow of an electric current through a nerve is unattended by muscular contraction; it has likewise been seen that very slow changes in the strength of the current are similarly unaccompanied by the manifestations of ordinary stimulation; but sudden changes in the strength, whether in the direction of increase or decrease, act as stimuli. However, while the passage of a constant current through a nerve does not manifest itself by contractions except at making and breaking, such a passage brings about a change in the tissue of the nerve known as *electrotonus*. It may be considered a state of electric tension. In the anodic area the excitability is diminshed (anelectrotonus); in the kathodic area it is increased (katelectrotonus). Nor is the electrotonic condition restricted to that portion of the nerve between the poles. Between the poles there is a point where the two influences—anelectrotonus and katelectrotonus—meet and there is neither increased nor decreased excitability. With weak currents this point is nearer the anode; with strong ones nearer the kathode. A descending current diminishes the excitability of a nerve; an ascending increases it. Prolonged application of electric stimuli will exhaust nervous excitability, but it may be restored by rest, or more quickly by an opposite current.

THE CEREBRO-SPINAL AXIS.

The cerebro-spinal axis embraces the nervous matter in the cranial cavity and in the spinal canal, excepting the roots of the cranial and spinal nerves. This axis consists of both white and gray matter. The white matter is made up of conducting elements; the gray matter consists of a number of connected ganglia. In the cord the white matter is situated externally; in the brain the gray. The encephalon is situated in the cranial cavity and consists of the cerebrum, the cerebellum, the pons Varolii, and the medulla oblongata. These different parts are connected with each other and with the cord by nerve fibers, and all

the cranial and spinal nerves are connected with gray matter either in the brain or in the cord, or in both. This gray matter exists for the purpose of receiving impressions and generating nerve force.

Membranes.—The encephalon and cord are covered by membranes for protection and for the support of vessels belonging thereto. These are (1) the dura mater, (2) the arachnoid and (3) the pia mater.

The **dura mater** is a dense fibrous structure surrounding the encephalon and adherent to the inner surfaces of the cranial bones. At certain points the two layers of which it is composed separate to form the venous sinuses. Processes of the internal layers also are sent inward between the two lobes of the cerebrum (falx cerebri), between the cerebrum and cerebellum (tentorium cerebelli and between the lateral halves of the cerebellum (falx cerebelli). This membrane passes through the foramen magnum to cover also the spinal cord, and to follow as a sheath the spinal nerves at their foramina of exit.

The **arachnoid** resembles the serous membranes. It covers the brain and cord underneath the dura mater without dipping into the sulci of the brain. Between it and the pia mater is what is known as the *subarachnoid space* containing the subarachnoid fluid. This fluid serves a mechanical purpose, equalizing pressure in different parts of the cerebro-spinal axis and protecting the nervous substance from injury by concussion, etc. Besides being found in the subarachnoid space, it occupies the ventricles of the brain and the central canal of the cord, communication between these being furnished by a small opening at the inferior angle of the floor of the fourth ventricle.

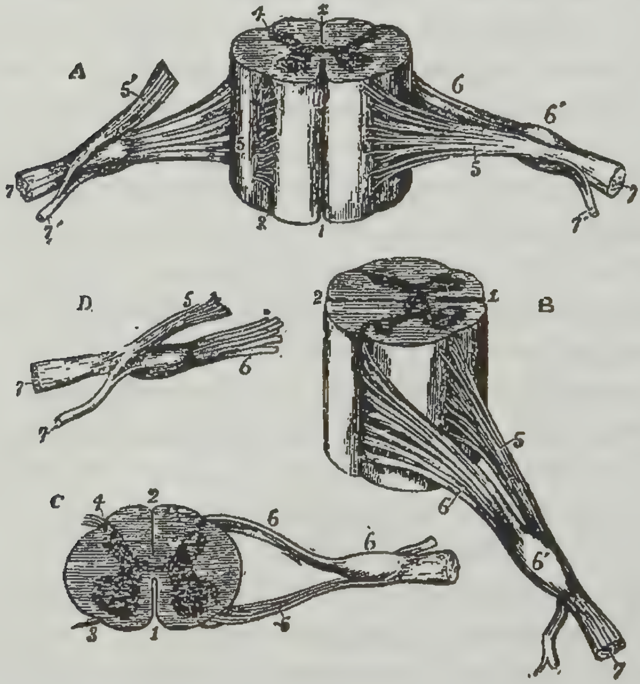
The **pia mater** is a very delicate structure dipping between the convolutions of nervous matter and lying in close contact with the external surface of the encephalon and cord. It is exceedingly vascular; indeed its main function is to support vessels belonging to the nervous substance underneath. Both the arach-

noid and the pia mater pass out at the foramen magnum with the dura to cover the cord.

The Spinal Cord.

The spinal cord occupies the spinal canal and is about eighteen inches long, extending from the foramen magnum to the lower border of the first lumbar vertebra. Its distal extremity is in the shape of a slender filament known as the *filum terminale*,

FIG. 69.



Different views of a portion of the spinal cord from the cervical region, with the roots of the nerves. (Slightly enlarged.)

In A, the anterior surface of the specimen is shown; the anterior nerve-root of its right side is divided; in B, a view of the right side is given; in C, the upper surface is shown; in D, the nerve-roots and ganglion are shown from below. 1, the anterior median fissure; 2, posterior median fissure; 3, anterior lateral depression, over which the anterior nerve-roots are seen to spread; 4, posterior lateral groove, into which the posterior roots are seen to sink; 5, anterior roots passing the ganglion; 5′, in A, the anterior root divided; 6, the posterior roots, the fibers of which pass into the ganglion 6′; 7, the united or compound nerve; 7′, the posterior primary branch, seen in A and D to be derived in part from the anterior and in part from the posterior root. (*Kirkes* after *Allen Thomson.*)

which is gray in color. The sacral and coccygeal nerves, having taken origin from the cord in the dorsal region, pass downward in the canal to find exit through the sacral and coccygeal foramina. This collection of nerves thus passing down is known as the *cauda equina*.

Gross Divisions of the Spinal Cord in Section.—Cross section of the cord reveals the division of its substance into two lateral halves connected by the *anterior* and *posterior commissures*. In the center of the cord, and between these commissures, is a small opening, the *central canal* of the cord, communicating with the fourth ventricle above. This division of the substance of the cord into lateral halves is effected by the two *median fissures*, *anterior* and *posterior*. The former is the more clearly marked, and is lined throughout with pia mater. It is bounded posteriorly by the *anterior white commissure*. The posterior median fissure is not lined with pia mater and extends anteriorly as far as the *posterior gray commissure*. It is to be noted that there are both anterior and posterior gray commissures, but only one white commissure (anterior), which is bounded posteriorly by the anterior gray commissure.

Besides the anterior and posterior median fissures there are also on each side *antero-lateral* and *postero-lateral* fissures, marking the lines of exit of the anterior and posterior roots of the spinal nerves. These are not well defined. They divide the cord into *anterior*, *posterior* and two *lateral columns*.

Arrangement of Gray Substance.—The disposition of the gray substance in the cord (in tranverse section) is somewhat after the manner of the letter H, each lateral portion representing the *anterior* and *posterior cornua* of gray matter for that side, and being connected to the corresponding portion of the other side by the commissures embracing the central canal. The anterior cornua are shorter and thicker than the posterior. From these issue the anterior and posterior roots respectively of the spinal nerves. The *cells* are: (1) Those in the anterior cornu;

(2) those in the posterior cornu; (3) those in the lateral aspect of the gray matter; (4) those at the inner base of the posterior cornu (Clarke's vesicular column).

The gray substance is made up of cells with, of course, the usual neuroglia and blood-vessels. The cells in the anterior cornua are larger in size and possess a greater number of poles than those in the posterior cornua; from their connection with the anterior (motor) spinal nerve roots they are called *motor* cells in contradistinction to the *sensory* cells in the posterior cornua which are connected indirectly with the posterior (sensory) nerve roots.

Degeneration.—Nerve fibers when separated from the cells of which they are outgrowths degenerate. Fibers have been said to degenerate in the direction in which they carry messages, but this is by no means always so. For instance, the parent cells for the fibers of the *posterior spinal roots* are in the ganglia on those roots near the cord, and section of the root beyond the ganglion causes degeneration of its fibers *peripherally*—which is in the opposite direction to the passage of impressions in them. Section of the posterior root between the ganglion and cord is followed by *centripetal* degeneration, and there is no centrifugal degeneration. The *anterior spinal root* fibers are outgrowths of cells in the anterior cornua of gray matter. Section of this root anywhere occasions *centrifugal* degeneration (Fig. 70).

Arrangement of the White Substance.—It is scarcely necessary to state that the white substance of the cord consists of nerve fibers with their usual accompaniments. It is external to the gray. The fibers are medullated, but have no sheath of Schwann.

The divisions of the cord already referred to are purely anatomical. Physiological and pathological researches warrant the further division of the white substance of the cord into eight columns for each side. The course of all the fibers in the white matter of the cord is by no means certain. The division here

given may not be strictly correct, but it probably receives as little adverse criticism as any of the others. Classified according to the direction in which their fibers degenerate after section the paths are: (I) *Degenerating downward,* (*a*) the column of Turck and (*b*) the crossed pyramidal tract; (II) *degenerating upward,* (*a*) the column of Goll and (*b*) the direct cerebellar

FIG. 70.

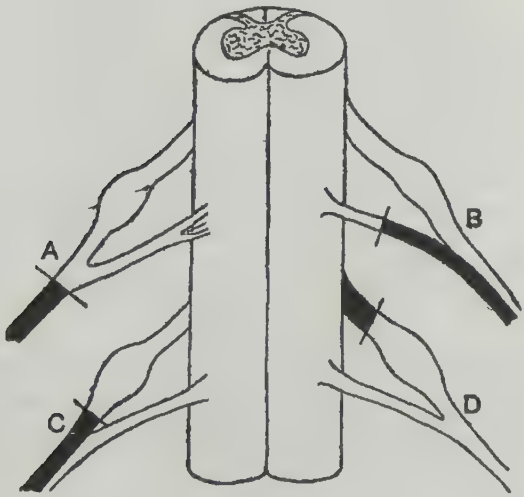


Diagram to illustrate wallerian degeneration of nerve-roots. (*Kirkes.*)

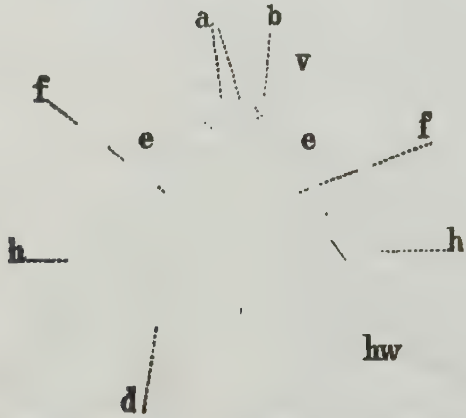
tract; (III) *degenerating in neither direction,* (*a*) the anterior fundamental fasciculus, (*b*) the anterior radicular zone, (*c*) the mixed lateral column and (*d*) the column of Burdach.

I. (*a*) The *column of Turck* occupies a position just lateral to the anterior median fissure and extends downward to the lower dorsal region. Its fibers decussate high up in the cord. This column is sometimes called the direct, or uncrossed, pyramidal tract, as distinguishing it from the other descending column. (*b*) The *crossed pyramidal tract* is external to the posterior cornu of gray matter and internal to the direct cerebellar tract. Its

fibers decussate in the anterior pyramids of the medulla oblongata.

II. (*a*) The *direct cerebellar tract* occupies the outer posterior part of the lateral column. Its fibers reach the cerebellum through the inferior peduncles, after having traversed the posterior pyramids of the medulla. This tract exists throughout the

FIG. 71.



Scheme of the conducting paths in the spinal cord at the 3d dorsal nerve.

The black part is the gray matter. V, anterior, hw, posterior root; a, direct, and g, crossed, pyramidal tracts; b, anterior fundamental fasciculus; c, Goll's column; d, column of Burdach; e, anterior radicular zone; f, mixed lateral tract; h, direct cerebellar tracts. (*Landois*, modified.)

length of the cord. (*b*) The *column of Goll* (postero-internal column) is situated posteriorly in a position corresponding to the column of Turck anteriorly—just lateral to the posterior median fissure. Fibers in this column extend from the upper lumbar region to the funiculi graciles of the medulla.

III. (*a*) The *anterior fundamental fasciculus* lies between the column of Turck internally and the anterior cornu and anterior roots of the spinal nerves externally. Its fibers are lost in the medulla above. (*b*) The *anterior radicular zone* is external to the anterior roots of the spinal nerves and anterior to the crossed pyramidal tract and the direct cerebellar fasciculus. Its fibers are lost in the medulla above. (*c*) The *mixed lateral column* is

just external to the main body of gray matter and does not reach the surface of the cord. Its fibers are likewise lost in the medulla oblongata. (*d*) The *column of Burdach* (postero-external column) is situated posteriorly in a location corresponding to the anterior

FIG. 72.

Course of the fibers for voluntary movement.

ab, path for the motor nerves of the trunk; *c*, fibers of the facial nerve; *B*, corpus callosum; *Nc*, nucleus caudatus; *G. i*, internal capsule; *N. l*, lenticular nucleus; *P*, pons; *N. f*, origin of the facial; *Py*, pyramids and their decussation; *Ol*, olive, *Gr*, restiform body; *PR*, posterior root; *AR*, anterior root; *x*, crossed, and *z*, direct pyramidal tracts. (*Landois.*)

fundamental fasciculus anteriorly—external to the column of Goll and internal to the posterior cornu. Its fibers reach the cerebellum through the inferior peduncles, having passed through the restiform bodies.

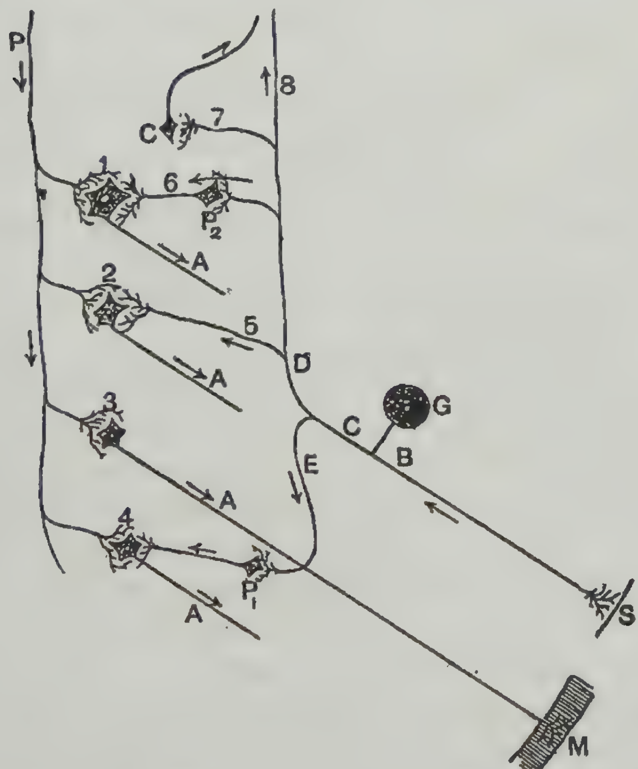
Functions of the Columns.—Remarks already made touching the direction of *degeneration* in the separate columns throw some light upon the physiological function of the fibers in each.

Motor impulses pass downward from the brain through certain fibers to the cells of the anterior cornua of gray matter in the cord, and are sent thence through the spinal nerves to the muscles. The paths in the cord conveying these impulses are found to be the **columns of Turck** and the **crossed pyramidal tracts,** and these are the only parts of the cord known so to act. Impulses to the upper segment of the cord may be conveyed by either of these columns, but impulses to the lower segment must follow the crossed pyramidal tract, since the column of Turck ceases to exist in the dorsal region. Only some 3–7 per cent. of motor fibers from the cortex are thought to enter the columns of Turck. The others decussate in the medulla and enter the crossed pyramidal tracts. In any case motor impulses originating in the brain and so conveyed are manifested on the side *opposite their cerebral origin*, since the fibers in both these tracts decussate in passing downward. It is a well known pathological fact that lesions of motor areas in the brain, or section of one lateral half of the cord, are followed by paralysis on the side opposite the lesion.

Following a motor fiber (A, Fig. 73) through the **anterior** root of a spinal nerve, it is found to originate from one of the large multipolar cells (3) in the anterior cornu of gray matter. Around these anterior horn cells (1, 2, 3, 4) arborize the end filaments of fibers which have come down through the cord from the brain. Some fibers have come down in the uncrossed pyramidal tract (column of Turck) on the side opposite the cells 1, 2, 3, 4, and crossed over to the same side through the anterior white com-

missure approximately on a level with the cells; others have decussated in the medulla, and come down in the crossed pyramidal tract on the same side as the cells. In both cases the fibers *originated* in the brain on the side opposite the cells around which

FIG. 73.



Course of nerve fibers in spinal cord. (*Kirkes* after *Schäfer*.)

they arborize in the cord. This is the connection which exists between the brain and the anterior root fibers.

Not all fibers in the anterior nerve roots are thus prolonged upward in the pyramidal tracts. The number of fibers in these roots is much larger than in the pyramidal tracts, and consequently some of them must end (originate) directly in the cells of the anterior cornua. Furthermore, it seems that some fibers

pass from the anterior nerve roots directly into the pyramidal tracts without being interrupted by motor cells.

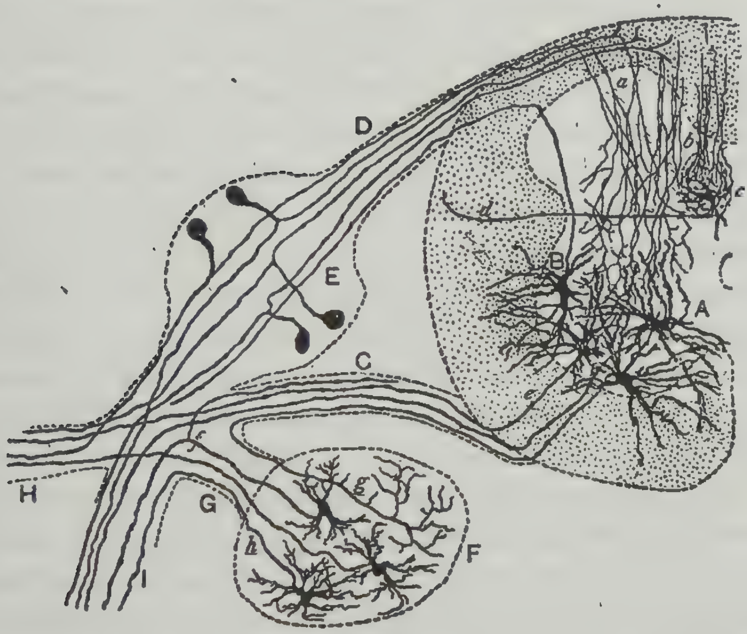
The **column of Turck** and the **crossed pyramidal tract** are, therefore, *the motor paths in the cord.*

Fibers entering the cord by the **posterior** roots send prolongations both upward and downward in the gray matter of the cord, and communicate by end arborizations with the small sensory cells in the posterior cornua and with cells in several other localities. (See Figs. 73, 80.) Reference to Fig. 73 will show that the connection of the anterior nerve fibers with the gray matter of the cord is simple, while that of the posterior is comparatively complex. 1, 2, 3, 4 are anterior horn cells. Each of these gives rise to an efferent fiber, one of which (A) is shown distributed to a muscle (M). Each of these cells also is surrounded by the end arborization of a fiber (P) from the cortex.

A fiber from the posterior root is also shown. It originates in a cell of the sensory ganglion (G). It bifurcates, one branch going to the surface (S), the other enters the cord and itself bifurcates. The branch (E) is short and arborizes around a small cell (P_1) in the posterior cornu, from which a new axis cylinder arises to arborize around the anterior horn cell (4). The other branch (D) travels upward in the posterior column of the cord. A collateral (5) is seen going to the anterior horn cell (2), one to the posterior horn cell (P_2) and another to a cell (C) in the inner base of the posterior cornu (in Clarke's column); from C an axis cylinder enters the direct cerebellar tract. The main fiber (8) may terminate in the gray matter of the cord above, or in the medulla. Impressions brought thus to the cord are carried to the opposite side and pass up through the gray matter in most part. The fibers decussate at no particular point, but throughout the length of the cord. However, some fibers bearing sensory impressions pass to the column of Goll and thus upward, while some also go to the encephalon by the direct cerebellar fasciculi and the columns of Burdach. Ex-

perimentally, decussation of sensory fibers is demonstrated (1) by longitudinal section of the spinal cord in the median line, which is followed by anesthesia on both sides below the section; and (2) by horizontal section of one-half of the cord, which is followed

FIG. 74.



Transverse section through half the spinal cord, showing the ganglia.

A, anterior cornual cells; B, axis-cylinder process of one of these going to posterior root; C, anterior (motor) root; D, posterior (sensory) root; E, spinal ganglion on posterior root; F, sympathetic ganglion; G, ramus communicans; H, posterior branch of spinal nerve; I, anterior branch of spinal nerve; *a*, long collaterals from posterior root fibers reaching to anterior horn; *b*, short collaterals passing to Clarke's column; *c*, cell in Clarke's column sending an axis-cylinder process (*d*) to the direct cerebellar tract; *e*, fiber of the anterior root; *f*, axis cylinder from sympathetic ganglion cell, dividing into two branches, one to the periphery, the other towards the cord; *g*, fiber of the anterior root terminating by an arborization in the sympathetic ganglion; *h*, sympathetic fiber passing to periphery. (*Kirkes* after *Ramony Cajal.*)

by anesthesia on the opposite side below the section. It is claimed that pain and temperature sensations decussate at once on reaching the gray matter, while sensations of touch, pressure and equilibration pass up on the same side until the medulla is

reached. Some afferent fibers are probably not continued upward to the brain either directly or indirectly.

It thus appears that we have no very *accurate* knowledge of the sensory paths in the cord. The **gray matter** seems principally concerned; but the **columns of Goll and Burdach** and the **direct cerebellar fasciculi** also convey afferent impressions. For both motor and sensory paths to the *cortex* see p. 278.

The **columns of Burdach** have been said to present no degeneration secondary to section. Trophic centers for their fibers must, therefore, exist above and below any given point of section. It is found that the fibers constituting these columns pass in and out along the cord between cells in different planes and acting as longitudinal commissural fibers. In locomotor ataxia the characteristic symptom is inability to coördinate the muscular movements—especially of the lower extremities; the characteristic lesion has been found to be in the columns of Burdach. This is of importance in determining the function of these columns, and, in fact, leads to the conclusion that their fibers assist in *regulating* and *coördinating* the voluntary movements. This opinion is further supported by the connection of these fibers with the cerebellum, which contains the center for muscular coördination—if such a center exist. The sense of *pressure* and the so-called *muscular sense* are probably connected with the fibers of this column, and these may be the only sensory impressions conveyed through the columns of Burdach.

The **anterior fundamental fasciculi,** the **anterior radicular zones,** and the **mixed lateral paths** degenerate in neither direction after section, their trophic cells existing at both extremities. They connect cells in the gray matter of the cord.

Functions of the Spinal Cord.—These are (1) conductions, (2) transference, (3) reflex action, (4) augmentation, (5) coördination, (6) inhibition of reflex acts, (7) special centers (Collin and Rockwell, modified).

1. *Conduction.*—This has been referred to in discussing the

white columns of the cord. This function makes it possible for the brain to receive impressions from and send impulses to the periphery. It is to be remembered that most of these impressions and impulses are interrupted by spinal nerve cells in their passage between brain and periphery.

2. *Transference.*—An impression reaching the gray matter of the cord may be transferred (not as in typical reflex action) so as to be felt in an entirely different region from that in which the irritation takes place. Hip joint disease often gives pain in the knee alone.

3. *Reflex Action.*—The cord may act as a center without the coöperation of the brain. Indeed, by no means do muscular movements cease immediately on removal of the encephalon if the cord and its nerves be left intact. An animal so mutilated possesses no sensation or volition, but for a time the sensory nerves will continue to convey impressions and the motor nerves impulses. Under these conditions impressions (as of heat) are conveyed to the cord by the afferent nerves; the gray matter of the cord receives the impressions and generates motor force which is sent out through the corresponding efferent nerves, and movements result. This is reflex action. The impression is reflected through the cord and manifested in motion *without the intervention of sensation or volition.* Reference to Figs. 73 and 80 shows how reflex action is anatomically possible through the cord connections. Typical reflex action requires anatomically (1) something to produce an impression, (2) a nerve terminal to receive it, (3) a centripetal fiber to convey it, (4) a center to receive and transform it, (5) a centrifugal fiber to convey it to the periphery and (6) a muscle to contract. This remark applies to reflex action connected with the cord, but by common consent reflex action is not limited to the cord and its connections.

If reflex action be defined as any involuntary manifestation of nerve force consequent upon the reception of an impression (general or special) by a nerve center, the term must be made to include

such phenomena as intestinal peristalsis, contraction and dilatation of the pupil, certain mental operations, etc. In reality most reflex acts are of a complex nature, involving associated action on the part of several neurons and being manifested frequently at several points. For example, a foreign body in the larynx causes reflexly not only closure of the glottis, but also the convulsive muscular contractions incident to coughing. The realm of reflex action is obviously a wide one.

It may be said that *ordinary* reflexes are *usually* under the direction of the cord, but this does not imply that the brain may not be concerned. Pricking the sole of the foot of a sleeping person will cause him to draw up his leg without the intervention of consciousness. Probably were he awake the withdrawal would still be a *reflex;* but he would certainly be conscious of the pain, though *after the act of withdrawal was accomplished.* Nor is reflex action by any means limited to the cerebrospinal system. Either of the two sytems, or both, may be concerned.

Now in order for reflex movements to occur, there must be a transference of impressions received by sensory cells to cells capable of giving origin to motor impulses. The cells communicate by their *collaterals*, which may be short or long, depending on the distance between the cells concerned. Cells in the gray matter of the cord are "connected" by such fibers, and they run largely in the white matter of the cord joining cells on different planes. They constitute the larger part of the anterior fundamental fasciculi, the anterior radicular zones, and the mixed lateral tracts, and *it is these paths which are mainly concerned in reflex action of the cord.*

4. *Augmentation.*—Sensory fibers, on reaching the cord, send prolongations both upward and downward in the gray matter. These prolongations, by their end arborizations, seem to communicate indirectly with *several* motor cells. In the simplest reflex movements connected with the spinal cord the muscular

activity is limited to the area corresponding to the distribution of the afferent nerve which has been irritated; but if the irritation be sufficiently increased other muscles in the same locality, or the corresponding muscles on the opposite side of the body, or even the whole musculature, may be thrown into action. This is explained on the ground that under favorable conditions of central excitability, strength of peripheral irritation, etc., the afferent impression is disseminated by collaterals throughout a large area of the cord (for example), and a large number of efferent cells are made to discharge. The reflex excitability of the cold is markedly increased by the administration of such drugs as strychnin. An animal so poisoned will be thrown into the most violent convulsions by so slight a sensory impression as a simple breath of air. Removal of the encephalon in inferior animals also exaggerates reflex excitability.

5. *Coördination.*—This has been referred to under the columns of Burdach. Coördination is "a repetition of ordinary reflex acts for our daily lives." No effort is necessary to coördinate the muscular movements of deglutition, respiration, walking, etc. These movements may be performed when the cerebrum is removed.

6. *Inhibition of Reflex Acts.*—This is not a function of the cord proper, but is directed by the cerebrum. A great many reflex movements may be inhibited by an act of the will, providing always they are due to contraction of striped muscle. The reflex acts of coughing or sneezing, or those resulting from tickling, for example, can be largely controlled. These are usually performed as reflex cord acts, but the brain may evidently assert its superiority over the cord and inhibit them.

7. *Special Centers.*—In the gray matter of the cord are found various centers for distinct acts such as *defecation*, *parturition*, *micturition*, etc. These are all connected with each other and with the encephalon and obey the usual laws of reflex action.

THE ENCEPHALON.

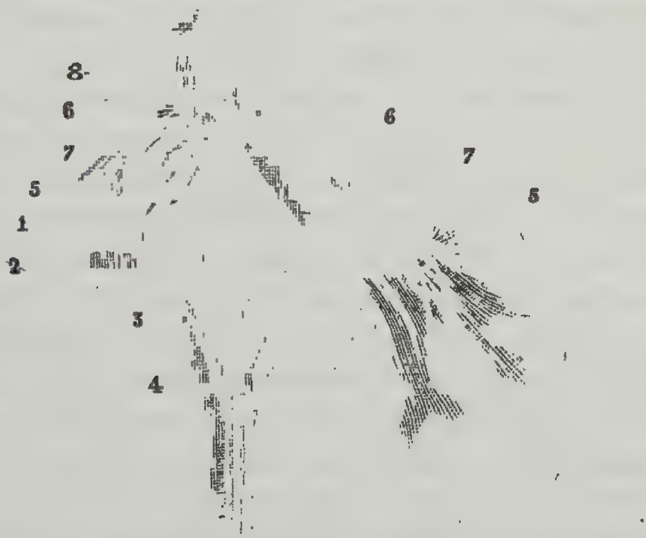
The encephalon is situated within the cranial cavity and is commonly called the brain. Its gross divisions are the *medulla oblongata*, the *pons Varolii*, the *cerebellum*, and the *cerebrum.* All the other divisions are in a measure subordinate to the cerebrum, though each division has individual functions. The human brain weighs about 49½ ounces in the male and about 44 in the female.

The Medulla Oblongata.

Anatomy.—The medulla oblongata, or bulb, joins the upper extremity of the spinal cord and extends to the pons above. It has a pyramidal shape, lies in the basilar groove of the occipital bone, and is slightly flattened antero-posteriorly. It is about an inch and a quarter in length, half an inch thick, and three-quarters of an inch broad above. The anterior and posterior median fissures of the cord are continued upward in the medulla; the central canal terminates in the inferior angle of the fourth ventricle. The anterior columns appear to be continuous with the anterior pyramids of the medulla. These *pyramids* are situated just lateral to the anterior median fissure. The *innermost* fibers of the pyramids are the continuations upward of the crossed pyramidal tracts, and are seen to decussate in the median line; the *outermost* fibers are the prolongations of the uncrossed pyramidal tracts. The *olivary bodies*, oval in shape, are just external to the anterior pyramids separated from them by a groove. The *restiform bodies* make up the postero-lateral portion of the medulla, and are external to the olivary bodies. They contain fibers from the columns of Burdach, and contribute largely to the formation of the inferior peduncles of the cerebellum. The restiform bodies, diverging as they ascend, form the lateral boundaries of the inferior division of the fourth ventricle. Beneath the olivary bodies, and between the anterior pyramids and the

restiform bodies, are the *lateral fasciculi*, or the *funiculi of Rolando.* They constitute the upward prolongation of all the antero-lateral portion of the cord which does not go to the formation of the anterior pyramids. Their chief importance is in the fact that they contain the centers for respiration. The *posterior*

FIG. 75.



Floor of the 4th ventricle and the connections of the cerebellum.

On the left side the three cerebellar peduncles are cut short; on the right the connections of the superior and inferior peduncles have been preserved, while the middle one has been cut short. 1, median groove of the 4th ventricle with the fasciculi teretes; 2, the striæ of the auditory nerve on each side emerging from it; 3, inferior peduncle; 4, posterior pyramid and clava, with the calamus scriptorius above it; 5, superior peduncle; 6, fillet to the side of the crura cerebri; 8, corpora quadrigemina. (*Landois.*)

pyramids are sometimes called the *funiculi graciles.* They join the restiform bodies and pass to the cerebellum.

The **fourth ventricle** deserves particular attention. It is a cavity on the posterior aspect of the pons and medulla extending from the upper limit of the former to a point on the latter opposite the lower border of the olivary body. It has the shape of two isosceles triangles placed base to base. The apex of the inferior triangle is at the calamus scriptorius, and its lateral boundaries are the diverging restiform bodies. The superior

peduncles of the cerebellum form the lateral boundaries of the superior triangle. The inferior triangle is covered by the cerebellum; the superior by the valve of Vieussens, which stretches between the superior peduncles. This ventricle communicates above with the third ventricle by the aqueduct of Sylvius, or the *iter a tertio ad quartum ventriculum;* below, with the central canal of the cord and with the subarachnoid space. The floor of the ventricle presents a longitudinal median fissure and numerous small elevations indicating the position of the nuclei of origin of certain of the cranial nerves.

The **gray matter** of the medulla has the same general distribution as that in the cord, but is by no means so regular in its disposition. The direction of the **white fibers** is not so uniform as in the cord. They run not only longitudinally, but transversely to connect the lateral halves, and in other directions to connect various centers situated in this part of the encephalon and to connect the medulla with other parts of the brain. The following is the relation of the columns of the cord to the medulla:

The *direct* and *crossed pyramidal tracts* pass to the encephalon constituting, in the medulla, the anterior pyramids—the direct, having decussated below, occupying here the outer portion of the pyramid, and the crossed decussating in the medulla and occupying the inner portion of the pyramid.

Those columns concerned in reflex action, the *anterior fundamental fasciculi*, the *anterior root zones*, and the *mixed lateral tracts* do not continue farther upward than the gray matter of the medulla.

The *columns of Goll* are continuous with the funiculi graciles.

The *columns of Burdach* and the *direct cerebellar fasciculi* pass to the cerebellum through the restiform bodies of the medulla.

Functions.—The functions of the medulla are (1) *conduction*, (2) *reflex action*, (3) to furnish *centers for special acts*.

1. As a *conductor* the medulla is absolutely necessary as a means of connection between the brain and cord. Sensory im-

pressions to and motor impulses from the brain must all pass through by this route.

2. As a *reflex nerve center* the medulla also resembles the cord, though impressions reflected through this organ are frequently much less simple than those reflected through the cord. Reflex action in the medulla is dependent on (3), to be noticed now.

3. The most important center presiding over coördinated movements is that for *respiration*. The encephalon may be cut away down as far as the medulla, and life will continue for a certain time. It is also true that the medulla itself may be gradually cut away from above downward until a certain point is reached, when respiration suddenly ceases. Likewise the spinal cord may be cut away upward till this point is reached, when the same results will follow. This is the true respiratory center, and is situated at the site of origin of the *vagi*. Its destruction is followed by an immediate suspension of respiration and consequent death by asphyxia, though there is no manifestation of the distress usually accompanying this condition. The sense of want of air is simply lost. There is one of these centers for each side, but they act synchronously, being connected by commissural fibers. Probably the usual mode of stimulation of the respiratory center is by *afferent impressions*, but it may also be stimulated directly, as by *deoxygenated blood*. Mutilation of the medulla, on account of the presence of this center, is followed by the nearest approach to instantaneous death, and the respiratory center has, therefore, been called the "vital spot," though death from any cause cannot be instantaneous.

Some other reflex centers are for *deglutition, sucking, secretion of saliva, vomiting, coughing, sneezing, dilatation of the pupil, secretion of sweat, secretion of glycogen, etc.* Typical of these is the reflex act of *sneezing*, in which case impressions are conveyed to the medulla by the nasal branches of the fifth nerve.

Additional centers in the medulla are those which preside over *inhibition* and *acceleration of the heart*, *vaso-motor* centers for the

vessel walls, and centers for special senses like *hearing* and *taste*. There is also said to be here a center controlling the production of *heat* by the tissues.

The Pons Varolii.

Anatomy.—The pons is situated just above the medulla oblongata at the base of the brain, and is frequently called the *great commissure*, for the reason that it contains white fibers connecting the two lateral halves of the cerebellum and the different portions of the cord and medulla with the parts of the brain above. It resembles the cord in having its *white matter* situated externally, while within its substance are a number of collections of *gray matter*. The longitudinal fibers are continuations upward of fibers from the olivary bodies and the anterior pyramids of the medulla and also of parts of the posterior and lateral columns of the cord. They pass through the crura cerebri to the brain.

Functions.—The anatomical structure and situation of the pons at once suggest that its function is to *transmit* motor impulses from and sensory impressions to the cerebrum.

The gray centers, however, indicate a further function of this organ. It is found that the removal of all parts of the encephalon above the pons does not deprive an animal of *voluntary motion* and *general sensibility*. It will be seen later that the integrity of the cerebrum is essential to any intellectual operation, and manifestly, under the conditions mentioned, there can be no voluntary motion which indicates any degree of *intelligence;* but the fact remains that the animal can perform movements which are different from the reflex movements depending on the presence of the cord when all other parts of the cerebro-spinal axis have been removed. The pons is apparently "an organ capable of originating impulses giving rise to voluntary movements, when the cerebrum, corpora striata and optic thalami have been removed, and it probably regulates the automatic voluntary movements of station and progression." (Flint.)

Nor can it be doubted that an animal thus mutilated feels *pain*. It is probable that the sensory impression is received by some of the gray centers in the pons itself, but not being conveyed to the cerebrum, is not remembered.

The Crura Cerebri, Corpora Striata, Optic Thalami, Internal Capsule and Corpora Quadrigemina.

It will be well before discussing the cerebrum to consider briefly other collections of gray and white matter in the neighborhood of the upper part of the pons.

The **crura cerebri,** passing upward from the anterior part of the pons, diverge to run apparently underneath the corpora striata and optic thalami in the direction of the cerebral hemispheres. They are about ¾ inch long and slightly broader above than below. The main bulk of each crus consists of *white fibers*, but a collection of *gray matter* (locus niger) divides the band into a lower or superficial section, called the *crusta*, and an upper or deep section, called the *tegmentum*. There is also some gray matter in the tegmentum proper. The fibers of the tegmentum are supposed to convey *afferent* impressions chiefly, and end for the most part in the *optic thalamus*, though some are continued to the cerebrum through the internal capsule. The fibers of the crusta are supposed to convey *efferent* impulses, and pass to the *corpus striatum* and the *cerebrum.*

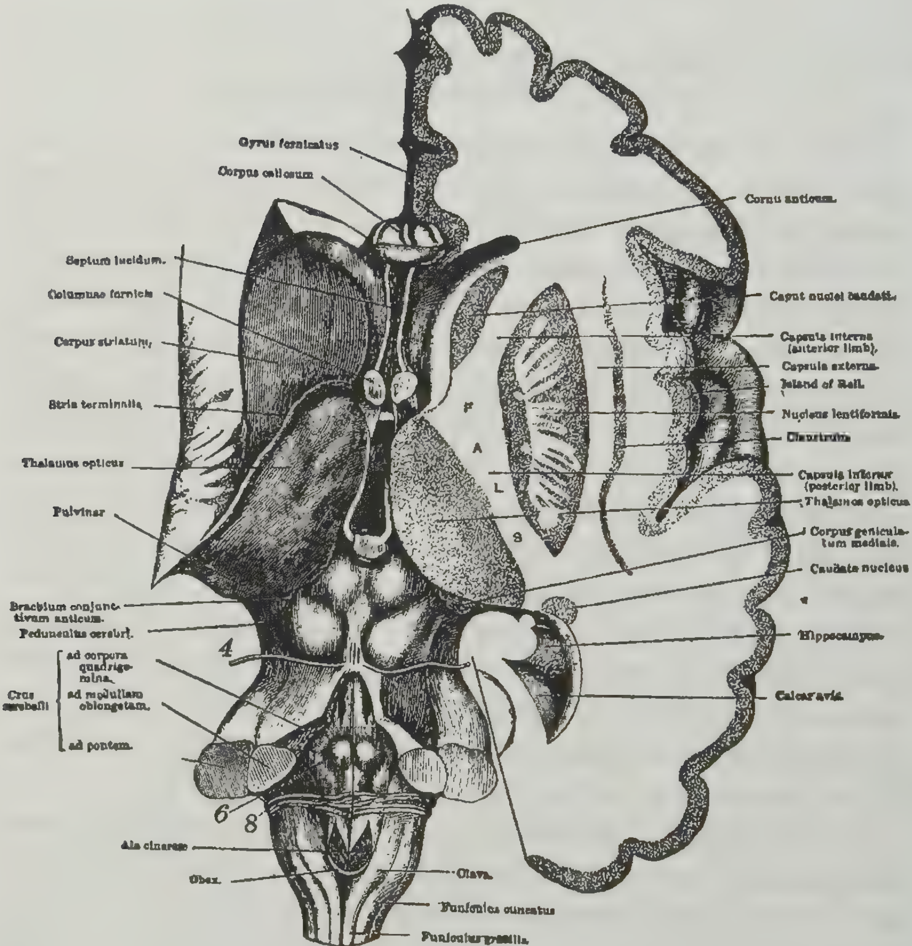
It is evident that the **function** of the crura is mainly to *conduct* messages to and from the parts above. It is said that the *locus niger* is concerned in coördination of the movements of the eye-ball and iris.

The **Corpora Striata, Optic Thalami** and **Internal Capsule** are closely related and are best considered together.

Each *corpus striatum* is pear-shaped with its large end forward and near the median line; the posterior small extremities are divergent from each other and embrace the two optic thalami. Externally they are white; internally white and gray elements

are mixed. Each is separated by the anterior limb of the internal capsule into two divisions, external and internal, known respectively as the *lenticular* and *caudate nuclei.* (See Fig. 76.)

FIG. 76.



Human brain, with the hemispheres, removed by a horizontal incision on the right side.

4, trochlear; 8, acoustic nerve; 6, origin of the abducens; F, A, L, position of the pyramidal (motor) fibers for the face, arm and leg; S, sensory fibers. (*Landois.*)

The *optic thalami*, one on either side, have an oval shape and rest upon the crura cerebri between the posterior extremities of

the two corpora striata. Most of their external surface is white; internally each possesses six gray nuclei.

Separating the two nuclei of the corpus striatum anteriorly, and the lenticular nucleus from the optic thalamus posteriorly, is a band of white fibers known as the *internal capsule.* The part between the two nuclei is the anterior limb; that between the lenticular nucleus and the optic thalamus is the posterior limb. These limbs, joining at an obtuse angle, constitute a bend in the internal capsule which is called the *genu*, or knee. The fibers of the capsule pass to the frontal, parietal and occipital lobes of the cortex, and in their course to these parts they diverge to form the *corona radiata.*

External to the lenticular nucleus is a band of white fibers known as the *external capsule.* In it is a longitudinal mass of gray matter, the *claustrum.* Fig. 76 shows the relations of these parts.

Functions.—The exact function of the *corpora striata* is a matter of some doubt. They have been considered the great *motor ganglia* of the base of the brain; but, although lesions here are followed by paralysis on the opposite side of the body, it is held that this phenomenon is due to the proximity of the internal capsule. The further fact that irritation of this organ is followed by muscular contractions does not prove that it ordinarily generates motor force, for many of the fibers from the motor cortical zone pass to or through the corpus striatum. This may be only a relay station, and the corpus may be quite subsidiary. It undoubtedly, however, is connected with *motion* in some way.

The precise function of the *optic thalami* is equally obscure. The relation of these organs to the tegmenta would suggest that they have something to do with the *sensory* fibers on their way to the cortex. It cannot be denied that they are concerned in sensation, since their removal is followed by crossed anesthesia. They may likewise be relay stations. Each sends fibers to the

cerebellum and contains one of the nuclei of origin of the optic nerve.

Regarding the function of the *internal capsule* it may be said that its fibers are in main part prolongations from the *crusta* and from the gray matter of the *corpora striata;* fibers also pass upward through it from the tegmentum and the optic thalamus. As a matter of fact, most of the fibers of the crura go directly into the corpora striata (motor) and the optic thalami (sensory), but some pass directly upward through the capsule. It is to be noted, however, that the capsule does not consist of these last named fibers alone, but of fibers from the corpora striata and optic thalami as well. Observations show that pathological lesions affecting the *anterior two-thirds* of the posterior division of the internal capsule are followed by paralysis of motion; that lesions affecting only the *posterior one-third* of the posterior division are followed by anesthesia; and that lesions affecting the *entire posterior limb* are followed by both paralysis and anesthesia—these phenomena always manifesting themselves on the side opposite the lesion only. This leads to a definite conclusion; viz., that efferent fibers occupy the anterior two-thirds and afferent fibers the posterior one-third of the posterior limb of the capsule.

Nothing conclusive can be said about the function of the *external capsule* or of the *claustrum.*

The **Corpora Quadrigemina,** two on each side, are prominences on the dorsal surface of the pons and crura above the aqueduct of Sylvius. They contain *white* and *gray* matter. The posterior tubercles are connected with the eighth nerve, the sensory tract, the temporal region of the brain, and the lateral corpora geniculata. The anterior tubercles are connected with the optic nerve, with the occipital region, and with the median corpora geniculata.

The *function* of the anterior of these bodies is mainly connected with the eye; the posterior are associated with the sense of hearing.

The Cerebrum.

The great size of the cerebral hemispheres in man obscures the fact that the different parts of the brain are disposed in a linear series; these, from before backward, are, the olfactory lobes, cerebral hemispheres, optic thalami, corpora quadrigemina, cerebellum, medulla oblongata. This arrangement exists in the human fetus, and persists throughout life in some of the lower animals.

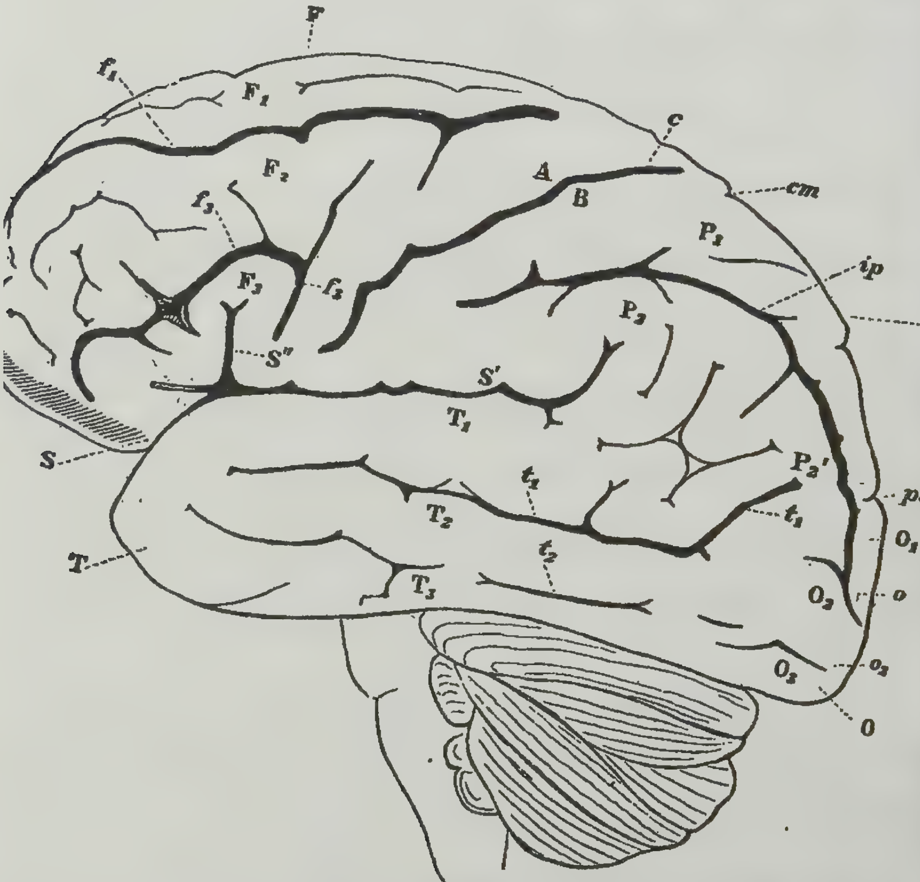
Anatomy.—The substance of each hemisphere is divided by fissures into five **lobes**—(*a*) *frontal*, (*b*) *parietal*, (*c*) *occipital*, (*d*) *temporo-sphenoidal* and (*e*) *central*. The main **fissures** are four in number—(1) The *fissures of Sylvius* running from the front and under part of the brain backward, outward and upward; (2) the *fissures of Rolando* running from the median line near the center of the longitudinal fissure forward, outward and downward; (3) the *parieto-occipital fissure*, little of which is evident upon the surface of the brain, but which appears on longitudinal section separating the occipital and parietal lobes; (4) the *calloso-marginal fissure*, also evident only on the internal aspect of the hemisphere, parallel with and above the corpus callosum. (Figs. 77, 78.)

(*a*) The *frontal lobe* is bounded internally by the longitudinal fissure, posteriorly by the fissure of Rolando and below by the fissure of Sylvius. On its surface are seen three convolutions, approximately parallel, called the *superior*, *middle* and *inferior frontal convolution*, and occupying positions which their names indicate. In addition the posterior portion of this lobe is occupied by the *ascending frontal*, or the *anterior central convolution*, lying just in front of the Rolandic fissure.

(*b*) The *parietal lobe* is bounded anteriorly by the fissure of Rolando, internally by the longitudinal fissure, posteriorly by the parieto-occipital fissure and below by the fissure of Sylvius. Just behind the fissure of Rolando is the *ascending parietal*, or

posterior central convolution, above, this is continuous with the *upper parietal convolution*, below which is the inferior parietal lobule separated from the preceding by the *intra-parietal sulcus*. This inferior parietal lobule winds around the posterior part of

FIG. 77.



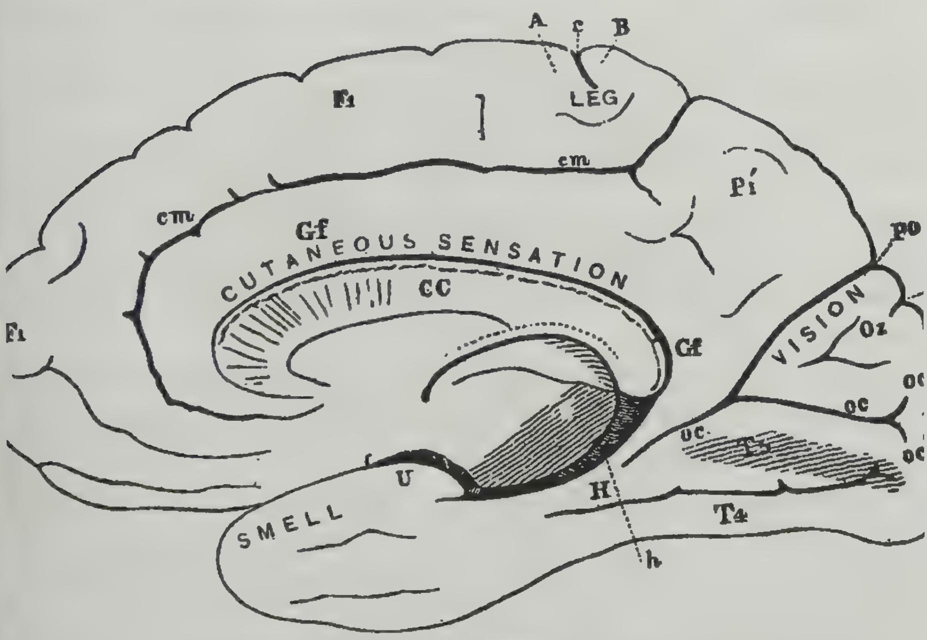
Left side of the human brain (diagrammatic).

F, frontal; P, parietal; O, occipital; T, temporo-sphenoidal lobe; S, fissure of Sylvius; S′, horizontal; S″, ascending ramus of S; *c*, sulcus centralis, or fissure of Rolando; A, ascending frontal, and B, ascending parietal convolution; F_1, superior, F_2, middle, and F_3, inferior frontal convolutions; f_1, superior, and f_2, inferior, frontal fissures; f_3, sulcus precentralis; P, superior parietal lobule; P_2, inferior parietal lobule, consisting of P_2, supra-marginal gyrus, and P_2', angular gyrus; *ip*, sulcus interparietalis; *cm*, termination of calloso-marginal fissure; O, first; O_2, second; O_3, third occipital convolutions; *po*, parietal-occipital fissure; *o*, transverse occipital fissure; o_2, inferior longitudinal occipital fissure; T_1, first; T_2, second; T_3, third, temporo-sphenoidal convolutions; t_1, first; t_2, second, temporo-sphenoidal fissures. (*Landois.*)

the fissure of Sylvius, and is divided into the *supra-marginal* convulution, embracing the short arm of this fissure, and the *angular* convolution connecting below with the temporal lobe.

(*c*) The *occipital lobe* is situated posteriorly below the parieto-

FIG. 78.



Median aspect of the right hemisphere.

CC, corpus callosum divided longitudinally; Gf, gyrus fornicatus; H, gyrus hippocampi; h, sulcus hippocampi; U, uncinate gyrus; cm, calloso-marginal fissure; F, first frontal convolution; c, terminal portion of fissure of Rolando; A, ascending frontal; B, ascending parietal convolution and paracentral lobule; P_1', parecuneus or quadrate lobule; Oz, cuneus; Po, parieto-occipital fissure; o′, transverse occipital fissure; oc, calcarine fissure; oc′, superior; oc″, inferior ramus of the same; G, gyrus descendens; T_4, gyrus occipito-temporalis lateralis (lobulus fusiformis); T_5, gyrus occipito-temporalis medialis (lobulus lingualis). (*Landois.*)

occipital fissure and external to the median fissure. It presents three convolutions, the *superior*, *middle* and *inferior*.

(*d*) The *temporo-sphenoidal lobe* is below the fissure of Sylvius in front of the occipital lobe. It likewise presents *superior*, *middle* and *inferior* convolutions.

(*e*) The *central lobe*, or *island of Reil*, presents the *gyrus forni-*

catus, a convolution curving around the corpus callosum; the *marginal convolutions* beyond the calloso-marginal fissure from the preceding and between it and the edge of the longitudinal fissure; the continuation of the *parieto-occipital fissure* running downward and forward to meet the calcarine fissure, between which is the *cuneus;* the internal aspect of the temporal lobe, the *uncinate gyrus.*

Structure.—The cerebral hemispheres are composed of *white* and *gray* matter, but here the gray matter is situated externally. To increase its amount, with economy of space, the gray matter is thrown into many *convolutions*, to some of which reference has been made. The sulci separating these convolutions have a depth in the average human brain of about one inch. The thickness of the gray matter of the cortex varies from $\frac{1}{12}$ to $\frac{1}{8}$ in., being thinnest in the occipital and thickest in the front.parietal region.

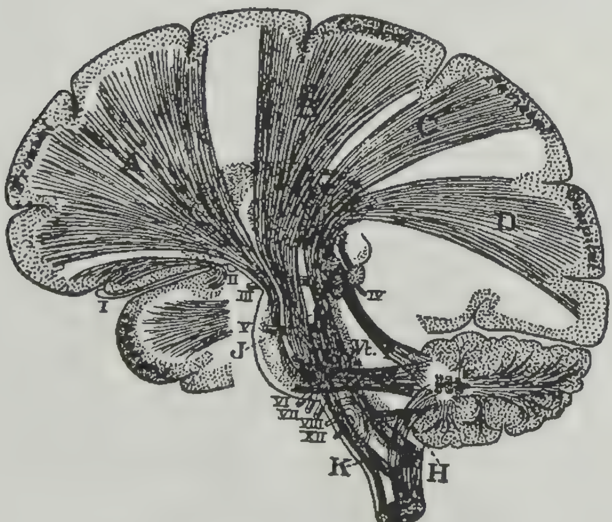
The *cells* found in the superficial and deep portions of the gray matter are not uniform in size or shape. In a general way it may be said that they increase in size as the surface is left, but in addition to the comparatively large cells in the deep parts there are also numbers of small ones. Passing in the same direction there are found in succession small pyramidal, larger pyramidal, and irregular branching cells.

Fibers from the Cerebrum.—Fibers pass from each cerebral hemisphere to (*a*) the spinal cord, (*b*) the cerebellum, (*c*) the opposite cerebral hemisphere, and (*d*) different parts of the same hemisphere.

(*a*) Fibers converge from the *anterior* and *middle* (particularly the latter) parts of the cortex to pass by the *corona radiata* to the *corpora striata*, from which fibers are continued to the *crusta*, *pons*, *pyramids of the medulla* and *pyramidal tracts* of the cord; most of these pass down through the *internal capsule* to reach the corpora striata. From the same regions also some fibers pass directly through the internal capsule, without connection

with the corpora striata, to be actually continuous themselves with fibers which, following the same course downward, are found in the pyramidal tracts of the cord. All fibers passing from these cortical areas mentioned through the internal capsule occupy the anterior two-thirds of the posterior division of that

FIG. 79.



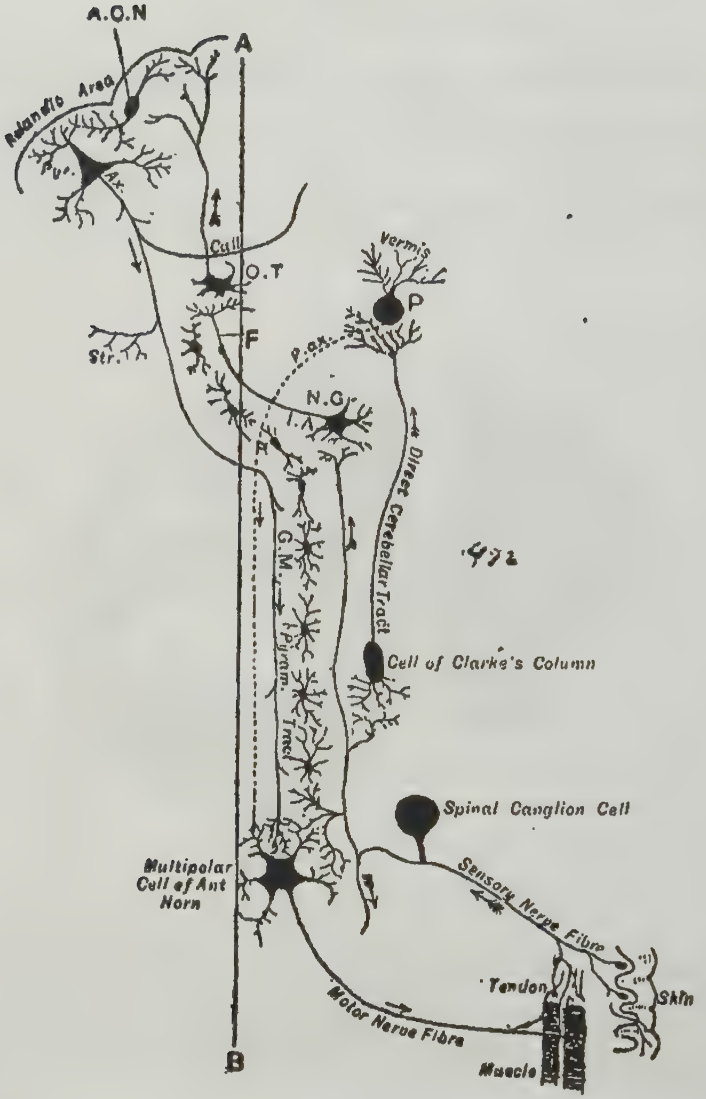
Scheme of the projection fibers within the brain. (*Starr.*)

Lateral view of the internal capsule; A, tract from the frontal gyri to the pons nuclei, and so to the cerebellum; B, motor tract; C, sensory tract for touch (separated from B for the sake of clearness in the scheme); D, visual tract; E, auditory tract; F, G, H, superior, middle, and inferior cerebellar peduncles; J, fibers between the auditory nucleus and the inferior quadrigeminal body; K, motor decussation in the bulb; At, fourth ventricle. The numerals refer to the cranial nerves. The sensory radiations are seen to be massed toward the occipital end of the hemisphere. (*Am. Text-Book.*)

tract. Furthermore, fibers from the *posterior* cortical area pass through the posterior one-third of the posterior division of the internal capsule to the *optic thalamus*, from which fibers pass through the *tegmentum* to the *pons* and *medulla* and are continuous with fibers from the *sensory* tracts of the cord. The decussation of all these fibers has been mentioned.

Fig. 80 taken in conjunction with Fig. 73 illustrates the most

FIG. 80.



Scheme of relationship of cells and fibers of brain and cord. (*Kirkes.*)

Pyr, cell of Rolandic area; *Ax*, its axis cylinder crossing the middle line AB, to enter one of the pyramidal tracts; the collateral *Call* goes to the cortex of the opposite hemisphere, while another, *str*, enters the corpus striatum. The axis cylinder arborizes around an anterior horn cell, whence a motor fiber goes to the muscle.

The axis cylinder from the spinal ganglion cell is represented as bifurcating and sending one branch to the periphery and one to the cord; the latter itself bifurcates, the lower division ending as shown better in Fig. 73. N.G, cell in posterior cornu of the cord or posterior column of the bulb. The distance of this cell from the point of entrance of the axis cylinder into the cord may be great or small. Note the collaterals from it in Fig. 73. I.A, decussating fiber ending at cell in optic thalamus, O.T, from which a fiber passes to the cortex. A collateral is shown passing from the ascending sensory fiber to a cell of Clarke's column, whence a fiber passes to a cell, P, of the cerebellum.

recent ideas of the motor and sensory connections between brain and cord and the motor and sensory paths in the cord.

(*b*) Fibers from the *anterior portion* of the frontal lobe pass through the *anterior* limb of the internal capsule and seem to end in the gray matter of the pons and there to communicate with the cerebellum through the middle peduncles. Fibers also pass from the temporo-sphenoidal lobes and from the caudate nuclei of the corpora striata to the cerebellum on the opposite side. The connection is crossed in all these cases.

FIG. 81.

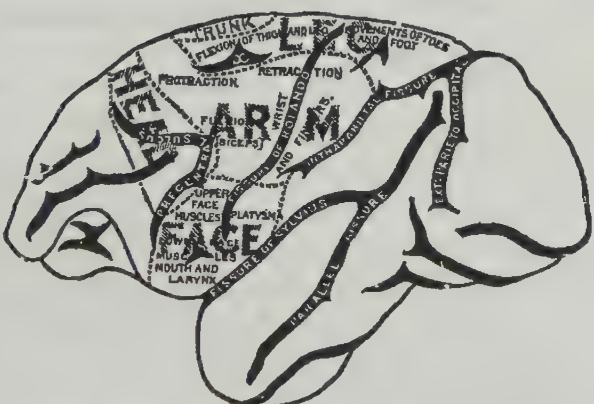


Diagram of the motor areas on the outer surface of a monkey's brain. (*Landois* after *Horsley* and *Schafer*.)

(*c*) Transverse fibers in the *corpus callosum* connect all parts of the two lateral hemispheres. Besides these commissural fibers there are those of the anterior and posterior white commissures. Fibers in the anterior connect the temporo-sphenoidal lobes and probably the corpora striata with each other; fibers in the posterior connect the temporo-sphenoidal lobes with the optic thalami of the opposite side.

(*d*) The *arcuate* fibers connect different convolutions of the same lobe and the convolutions of different lobes with each other. Some of these are in the *fornix*, in the *corpus callosum*, and in

FIG. 82.

Side view of the brain of man, with the areas of the cerebral convolutions according to Ferrier. (*Brubaker.*)

The figures are constructed by marking on the brain of man, in their respective situations, the areas of the brain of the monkey as determined by experiment, and the description of the effects of stimulating the various areas refers to the brain of the monkey.

1, advance of the opposite hind limb, as in walking; 2, 3, 4, complex movements of the opposite leg and arm, and of the trunk, as in swimming; *a*, *b*, *c*, *d*, individual and combined movements of the fingers and wrist of the opposite hand. Prehensile movements. 5, extension forward of the opposite arm and hand; supination and flexion of the opposite forearm; 7, retraction and elevation of the opposite angle of the mouth by means of the zygomatic muscle; 8, elevation of the alæ nasi and upper lip, with depression of the lower lip on the opposite side; 9, 10, opening of the mouth, with (9) protrusion and (10) retraction of the tongue; region of aphasia; bilateral action; 11, retraction of the opposite angle of the mouth, the head turned slightly to one side; 12, the eyes open widely, the pupils dilate, and the head and eyes turn toward the opposite side; 13, 13', the eyes move toward the opposite side, with an upward (13) or downward (13') deviation; the pupils are generally contracted; 14, pricking of the opposite ear, the head and eyes turn to the opposite side, and the pupils dilate widely.

other parts, as well as running along the concave surface of the cortex.

Cerebral Localization.—There are certain cortical areas which have certain fixed functions. There are certainly such areas for *motion* and for the reception of impressions conveyed by the nerves of *special sense;* areas for the reception of impressions conveyed by the nerves of *general sensation* have not been definitely determined.

Motor Centers.—Electrical stimulation of the convex surface of the cerebrum shows that the anterior part is *motor* and the posterior part *non-motor;* that stimulation of the motor portion produces *muscular* contractions on the opposite side of the body, that stimulation in the same spot is always followed by the *same contractions;* and that when the current is quite weak the contractions are limited to *distinct* muscles or sets of muscles. It may be further said that while experiments establishing these facts have been largely limited to inferior animals, the deductions have been made applicable to man by pathological observations and by the fact that in different animals stimulation of anatomically corresponding parts is followed by corresponding results. Destruction of motor areas is followed by descending secondary degeneration of fibers through the *corona radiata*, *internal capsule*, *crura cerebri* (*crusta*), *anterior pyramids of the medulla and the pyramidal tracts of the cord;* the resulting paralysis is on the side *opposite the lesion.*

The *motor cortical zone*, so far as can now be said, corresponds to the ascending frontal and parietal convolutions on either side of the fissure of Rolando, to the paracentral lobule, and possibly to a small area in front of the ascending frontal convolution. From above downward, on either side of the Rolandic fissure are areas presiding over the movements of the *leg*, *arm* and *face.*

More specific information as regards areas controlling various movements may be obtained by reference to Fig. 82.

Various kinds of *monoplegia* (crossed) are caused by lesions,

as hemorrhage, in localized parts of the motor area; there may be facial, brachial, crural, brachio-facial monoplegia, etc. There can be no doubt that from the motor cortical zone pass the fibers which constitute the pyramidal tracts of the cord.

Sensory Centers.—Centers for the reception of impressions giving rise to *general sensation* may exist. Fibers from the *temporo-sphenoidal* and *occipital lobes* pass through the posterior third of the posterior division of the internal capsule, and it may, therefore, be assumed that these parts of the cerebrum are connected with general sensation.

Special Centers.—Besides these areas for motion and general sensation, special centers certainly exist.

The *Optic Center* is in the occipital lobe, probably in the *cuneus*. Removal of the right occipital lobe is followed by left hemiopia and vice versa; removal of both causes total blindness.

The *Olfactory Center* is probably on the inner surface of the anterior extremity of the *uncinate gyrus* (inner extremity of the temporal lobe).

The *Gustatory Center* is supposed to be in the *temporal lobe* very near the preceding.

The *Auditory Center* is located in the superior and middle convolutions of the *temporo-sphenoidal lobe.*

The *Center for Cutaneous Sensations* cannot be strictly limited, though it is said to correspond with the *motor area*.

The *Center for Muscular Sensations* is thought to be in the *lower parietal region.*

The Speech Center.—One may not be able to speak because he cannot control the muscles usually involved in such an act, or because he has no comprehension of the meaning of words, or because he is incapable of forming the idea which links the reception of the impression and the muscular act. *Aphasia* is the term generally applied to inability to express one's self by language. It is to be distinguished, however, from *aphonia*, which is simply a loss of voice. *Ataxic aphasia* is an inability

to express ideas only by reason of muscular incoördination; a person so affected may use words, but he cannot tell *what* sounds he is going to utter; his ability to receive ideas is unimpaired, and he can express his own ideas in writing. When there is inability to express ideas in writing, because of muscular incoördination, a condition of *agraphic aphasia* is said to exist. There are also cases in which a person cannot comprehend ideas expressed in language and cannot express himself by either speaking or writing; this is known as *amnesic aphasia*. It is not impossible that in some instances ideas may be received and there still be an inability to express one's self in any way. It is noted that when the hemiplegia accompanying the aphasia is marked the form is usually ataxic; when there is no hemiplegia the aphasia is usually amnesic.

The part of the brain presiding over speech is in the *left third frontal convolution near the island of Reil.* In left-handed persons its usual situation is almost certainly at a corresponding point on the right side. Why the center is unilateral has not been explained. It may be that it was originally bilateral, and the growth of the right has been stopped by the superior development of the left side of the brain. It is at least noticed that the right instead of the left side of the brain is heavier in left-handed persons. Fibers from this center (Broca's convolution) pass through the anterior part of the posterior division of the internal capsule to reach the left crus, leaving which they enter the pons to decussate and go to the right side of the medulla.

Functions of the Cerebrum.—The superior development of the intellect in man is the most predominant characteristic distinguishing him from the lower animals. That many such animals are possessed of a certain degree of intelligence is not usually denied; and the *nature* of their mental operations, though they are insignificant as compared with man's, may be admitted as identical with his. The most striking difference in the nervous system of man as compared with that of inferior animals

is the large size of the cerebrum in the former. This is not surprising when it is admitted that in the substance of this part of the encephalon is the seat of those faculties which manifest themselves in mental operations.

The seat of the changes, if they be changes, which result in mental operations is supposed to be in the *frontal lobes;* these are insensible and inexcitable, but severe injury to them, as by hemorrhage, is followed by a cessation of mental activity; congenital defects also cause a corresponding decrease in the mental caliber.

From what has been said it is evident that the cerebral hemispheres are capable of *generating motor impulses and receiving impressions general and special;* but predominating in importance over these functions is the fact that the gray substance of the cerebrum is essential to the exercise of the *intellect*—even to the existence of that indefinite something called the mind.

It is by the cerebrum that we *perceive* and *retain* impressions, that we understand, imagine, reflect, reason and judge, and thus concoct and issue the mandates of our *will.* It is the link which connects our impressions and our purposeful actions.

In animals upon which experiments have been made it is found that life may persist for a time after the removal of the hemispheres, and that, outside of the cessation of mental activity, the results are not so marked as one would on first thought suppose. *Stupor* and *absence* of the ordinary *instinctive acts* (as corresponding in a way with acts of the will in man) are noted, but *voluntary motion* and *general sensibility are not destroyed,* and may be but little interfered with. Of course there is no voluntary motion in the sense of carrying out the behests of the *will,* for the organ of the will is destroyed; nor is there any *record* of painful impressions, for the organ of memory is absent. But the animal can perform various consecutive and coördinate movements, such as walking, swimming, etc. For example, a pigeon thus mutilated will fly when thrown into the air. This does not

argue any mental operation. A person does not ordinarily apply his *mind* to the act of walking or standing; his mental faculties may be as completely engaged with the deepest thoughts of psychology, literature, medicine or other subjects while walking as at any other time. True, he probably started with some fixed purpose to go in some particular direction to some definite place, but the act of progression does not *per se* require fixed attention on his part. So in the case of the pigeon; it does not, *make up its mind* to fly at all; and it will not fly without being thrown into the air, or the application of some other similar stimulus; nor does it fly in any particular direction, or to any particular place. It is reduced to the condition of a "mechanism without spontaneity." It can perform voluntary movements, but cannot *originate* them without external intervention.

Animals which have been subjected to the operation mentioned undoubtedly feel *pain*. They move away or cry out on being burned, for example. The coördination of their movements and the cries contrast with the phenomena (reflex) following such stimulation when only the cord is left. It was noted above that impressions in these cases are probably received by the gray matter of the pons and not recorded.

The special senses of *sight* and *hearing* remain after the removal of the cerebrum. The same is probably true of *taste* and *smell*.

It would seem that the cerebrum is a kind of storehouse in which are kept all the materials necessary for the performance of all kinds of *pre-determined* acts, whether they manifest themselves in speech, or thought, or muscular action. What excites these materials to activity—*i. e.*, what excites a voluntary act—is not clear. We know certain things will usually excite a certain train of thought, or cause us to *will* to do or say certain things. Such phenomena are akin to, if not identical with, reflex action. These manifestations of our voluntary power are due to impressions conveyed by afferent fibers to the cortex;

indeed it may be that every afferent fiber in the system exerts an influence thus indirectly upon the organ of the will, and the impressions conveyed by them are reflected in one's character and life. But it cannot be said that all voluntary activity is thus of a reflected nature; there is some cause other than the reception of afferent impressions which sets the will in operation.

Connection Between the Brain and Intelligence.—It is claimed that a single hemisphere is capable of performing all the ordinary intellectual acts as well as both; and atrophy, or destruction otherwise, of one hemisphere has frequently been noticed to entail no mental defect. But whether the mind under such conditions would be equal to the highest intellectual attainments is doubtful. It would seem that in health the brain unites the impressions received by the two sides (as, *e. g.*, through the optic nerves), and the resulting idea is a single one; that is to say, a person does not have two opposing ideas about the same thing at the same time; the two hemispheres seem to agree.

In a general way, it may be stated that the degree of intelligence corresponds to the weight of the brain, though to this rule there are many exceptions. It may be more properly said that the development of the intellectual faculties is greater as the area of gray matter is increased by the convolutions of the cortex. Idiots' brains are usually, though not by any means invariably, much below the average weight.

A difference in intellectual vigor may be present in persons whose brains have the same weight and even the same amount of gray matter. A difference in the *quality* of the gray substance may in such cases account for the varying results. It is a matter of common observation that mental exercise increases mental vigor and capacity, just as muscular exercise develops muscular strength. It is difficult to reach a conclusion as to whether there is an increase in the *amount* of gray substance or whether that already present is endowed with additional power.

The Cerebellum.

Anatomy.—The cerebellum, or little brain (see Fig. 75), is situated beneath the occipital lobes of the cerebrum, weighs some 5¼ ounces in the male to 4½ ounces in the female, and consists of a central and two lateral lobes. It is composed of white and gray matter, the latter being, with the exception of the corpora dentata in the lateral lobes, situated externally. The convolutions on its surface are much finer than are those on the cerebral surface. It is separated from the parts above by the tentorium cerebelli, a process the of dura mater.

Fibers.—The fibers passing away from the cerebellum are collected into three bundles on each side, known as the superior, middle and inferior peduncles. The *superior peduncle* has a direction forward and upward to reach the crus and optic thalamus; fibers in it connect the cerebellum with the cerebrum. Certain of these decussate underneath the corpora quadrigemina with corresponding fibers from the opposite side, so that each side of the cerebellum is connected with both sides of the cerebrum. Attention has been called to fibers passing down from the cerebrum through the pons to the cerebellum. Fibers in the *middle peduncle* connect the two lateral halves of the cerebellum through the pons. Fibers in the *inferior peduncle* are continuous below with fibers in the posterior columns of the cord through the restiform bodies of the medulla.

Function.—The only characteristic phenomenon invariably following removal of the cerebellum is an inability to *coördinate the voluntary muscular movements*. The foot, for example, can be raised, and the voluntary muscular act concerned in raising it may be as vigorous as ever, but the animal cannot so govern his movements as to know where he put it down. Even the coördination necessary in standing is lost, and the maintenance of the equilibrium is very difficult, if not impossible. The so-called muscular sense is abolished, and, while the power to contract

the muscles remains, the animal cannot contract them in a regular or coördinate manner. When it is remembered that well-nigh every voluntary act requires concerted or consecutive muscular movements some idea is gotten of the helpless condition sequent upon such a lesion. If it be granted that there is a center presiding over the coördination of the voluntary muscles, that center is in the cerebellum, and an animal deprived of this organ is as powerless, so far as this function is concerned, as a person is to see when the optic centers are destroyed. Its action is crossed.

It has been noted already that lesions of the posterior white columns of the cord are followed by disturbances of coördination, and that the cerebellum is connected with these columns through the inferior peduncles and restiform bodies. Fibers in these columns serve only as anatomical connections by which the coördinating center communicates with the muscles whose movements it is to regulate, and of necessity any lesion of these fibers destroying that connection is followed by the loss of control of the center over the muscles. However, in degeneration of the posterior columns (locomotor ataxia) an *effort* at coördination can be made, so that progression is possible by the aid of fixed attention. It is possible also that the coördinating messages are carried in such cases by the motor fibers, though in an unsatisfactory manner.

It has been supposed that the cerebellum is in some way connected with the *generative function*, and this much is probably true, though the evidence submitted is not sufficient to warrant the assumption that the cerebellum is the seat of the sexual instinct.

THE CRANIAL NERVES.

The cranial nerves, twelve in number on each side, take their origin from some part of the encephalon, pierce the dura mater and leave the skull by various openings. They have been num-

bered from before backward in the order in which they pass through the dura mater. Their names, indicating something of their function, and corresponding to their numbers, are as follows:

I. **Olfactory.**
II. **Optic.**
III. **Motor Oculi Communis.**
IV. **Patheticus (Trochlearis).**
V. **Trifacial (Trigeminus).**
VI. **Abducens.**
VII. **Facial.**
VIII. **Auditory.**
IX. **Glosso-pharyngeal.**
X. **Pneumogastric (Vagus).**
XI. **Spinal Accessory.**
XII. **Hypoglossal.**

The point at which one of these nerves can be seen to issue from the brain tissue is the apparent origin, while the gray nucleus, or nuclei, to which the fibers can be traced in the brain substance is the deep origin.

First Nerve (Olfactory).

Origin.—This is a nerve of special sense. Its **apparent origin** is by three roots. The *internal* root issues from the gyrus fornicatus; the *middle* from the under surface of the frontal lobe anterior to the anterior perforated space; the *external* from the temporo-sphenoidal lobe. These three roots unite to pass forward underneath the frontal lobe near the longitudinal fissure as the **olfactory tract.** The **deep origin** is unsettled.

Course and Distribution.—Reaching the upper surface of the cribriform plate of the ethmoid, the olfactory tract expands into the **olfactory bulb,** from the under surface of which are given off the special nerve fibers of the sense of smell. They are about

twenty in number and pass through the foramina in the cribriform plate to be distributed to the mucous membrane (Schneiderian) of the nose in three sets—an *inner* to the upper third of the septum, a *middle* to the roof of the nares, and an *outer* to the superior and middle turbinated bones and the ethmoid in front of them. The fibers are non-medullated.

Function.—The olfactory nerves are insensible and inexcitable. They are concerned with the sense of smell alone, and their integrity is necessary to the preservation of that sense. They convey to the brain impressions which are recognized as odors only. Removal of the olfactory bulb in a dog is evidently followed by a loss of the sense so characteristic of the animal: Furthermore, the olfactory bulbs in lower animals are shown to be developed in proportion to the acuteness of the sense of smell.

Second Nerve (Optic).

Origin.—This is the nerve of sight. Its **apparent origin** is from the anterior part of the optic commissure. **The optic commissure** occupies the optic groove on the superior surface of the sphenoid. It represents the union of the two **optic tracts** each of which, traced backward, is found to divide into two bands; the *external* takes its origin from the external geniculate body, from the pulvinar of the optic thalamus and from the superior corpus quadrigeminum; the *internal* comes from the internal geniculate body. These two, uniting, cross the crusta obliquely to reach the optic commissure, or chiasm. In the commissure the fibers from the inner margin of each optic tract pass to the other side of the brain, and may be called commissural fibers between the internal geniculate bodies. Some fibers anteriorly connect the two optic nerves with each other and are not properly part of the chiasm, but connect the two retinæ. The outer fibers of each tract pass to the nerve of the same side, while the central fibers decussate in the commissure with similar fibers

from the other tract and pass thus to the optic nerve of the opposite side. The **deep origin** is indicated above.

Course and Distribution.—Each optic nerve leaves the front of the optic chiasm to pass out of the cranium and enter the orbital cavity by the optic foramen. Having pierced the sclerotic and choroid coats of the ball it expands into the **retina.**

Function.—The optic nerves have no properties other than the conveying to the brain of the special impressions of sight. Stimulation produces neither pain nor motion.

Third Nerve (Motor Oculi Communis).

Origin.—The third is a motor nerve. Its **apparent origin** is from the inner surface of the crus just in front of the pons Varolii. Its **deep origin** is in a nucleus just lateral to the median line beneath the aqueduct of Sylvius. Here decussation with fibers from the opposite side occurs. The fibers pass forward from this place through the locus niger and tegmentum to the point of apparent origin.

Course and Distribution.—Having traversed the outer aspect of the cavernous sinus, the third nerve divides into two branches which leave the cranial cavity by the sphenoidal fissure between the two heads of the external muscle of the eye. The *superior* division is distributed to the **superior rectus** and **levator palpebræ superioris**; the *inferior* separates into three branches, one of which is distributed to the **inferior rectus,** another to the **internal rectus,** and a third to the **inferior oblique.** From this last a branch is given off to the **lenticular ganglion** to form its inferior root.

Functions.—This nerve has no function other than to supply motion to the parts to which it is distributed. It is insensible at its root, but receives filaments from the fifth in the cavernous sinus, beyond which point stimulation produces pain as well as muscular contractions. The phenomena sequent upon section of the nerve are suggested in its distribution. (1) There is *ptosis*,

or dropping of the upper lid; for the lid is kept open by the levator palpebræ superioris. (2) There is *external strabismus*, because the external rectus is not supplied by this nerve and is unopposed by the internal rectus, the action of which is paralyzed. *Diplopia* is the consequence. (3) There is *inability to turn the ball except in an outward direction* because the muscles producing movements on the vertical and horizontal axes are deprived of innervation. (4) There is *inability to rotate the eye* in certain directions on the antero-posterior axis. The antagonist of the inferior oblique is the superior oblique, the tendency of which latter is to rotate the globe so as to make the pupil look downward and outward. When the inferior oblique is paralyzed the superior oblique is unopposed, it is impossible to rotate the ball as is usual in sidewise movements of the head, and *double vision* is the result. (5) There is *slight protrusion* of the whole ball from relaxation of the muscles. (6) The *pupil is dilated* and movements of the *iris* are interfered with. Stimulation of the third nerve contracts the pupil, but when it is cut the pupil does not respond to light. The ciliary nerves controlling the movements of the iris come from the ophthalmic ganglion of the sympathetic; to this ganglion goes a branch from the third nerve. It is known that the action of the sympathetic cannot be divorced from that of the cerebro-spinal system; and whether this influence of the third nerve is exerted directly upon the iris or indirectly through the ophthalmic ganglion is a matter of some obscurity. The fact that the action of the iris is not instantaneous strongly suggests control by the sympathetic.

The decussation under the aqueduct of Sylvius is evidenced by the reflex contraction of the pupil on the opposite side when the central end of a divided optic nerve is stimulated. The impulse is reflected through the third nerve. It is not to be understood, however, that the motor oculi is the only nerve capable of influencing movements of the iris. Section of the sympathetic in the neck contracts the pupil, even after section of the third.

Fourth Nerve (Patheticus).

Origin.—This is a purely motor nerve. Its **apparent origin** is behind the corpora quadrigemina from the valve of Vieussens. The two nerves decussate above this valve. Its **deep origin** is just below that of the third nerve beneath the aqueduct of Sylvius.

Course and Distribution.—Emerging from the valve of Vieussens the nerve winds around the superior peduncle of the cerebellum and the crusta immediately above the pons, and passes forward near the outer wall of the cavernous sinus to find exit from the cranial cavity by the sphenoidal fissure. Having entered the orbit, it runs forward to be distributed to the orbital surface of the **superior oblique.** In the cavernous sinus it receives fibers from the ophthalmic division of the fifth and from the sympathetic, and occasionally gives off a branch to the lachrymal nerve.

Function.—It supplies motor power to the superior oblique muscle alone. Remembering the origin and attachment of this muscle it is not difficult to fortell the consequence of lesions of the nerve. The action of the superior oblique is to rotate the ball upon an oblique horizontal axis so that the pupil will look downward and outward. This movement cannot be accomplished when the nerve is cut, and the inferior oblique asserts itself unduly to bring about an opposite effect. The ball cannot accommodate itself to movements of the head toward the shoulder, and double vision supervenes—unless the object be brought in the involuntary line of vision of the affected eye.

Fifth Nerve (Trifacial, Trigeminus).

The fifth is analogous to the spinal nerves (1) in rising by two roots, (2) in having a ganglion on its posterior root, and (3) in having a mixed function. The anterior root is small and **motor;** the posterior large and **sensory.**

Origin.—Its **apparent origin** is from the side of the pons above

the median line. The **deep origin** of the large, sensory root is in the pons immediately below the floor of the fourth ventricle and just internal to its marginal boundary. The small, motor root rises from a point just internal to the large root.

Course and Distribution.—The two roots, taking their origin as above described, pass through the dura just above the internal auditory meatus and run along the superior border of the petrous portion of the temporal bone to a point near its apex, where a large ganglion, the **semilunar** or **Gasserian,** is developed on the posterior root and occupies a depression on the bone for its reception. The motor root passes *beneath* the ganglion without being connected with it.

The posterior root will be first followed to its distribution.

From the anterior surface of the Gasserian ganglion are given off three branches—(1) **ophthalmic,** (2) **superior maxillary,** (3) **inferior maxillary.** After the inferior maxillary has left the cranial cavity it receives fibers from the small or motor root, but the other branches are composed entirely of fibers from the sensory root.

1. The **Ophthalmic Branch** passes forward along the outer wall of the cavernous sinus, divides into three branches—(*a*) **lachrymal,** (*b*) **frontal,** (*c*) **nasal**—and enters the orbit by the sphenoidal fissure. It communicates with the cavernous sympathetic, third and sixth nerves. (*a*) The **lachrymal** branch, running along the outer wall of the orbit, reaches the lachrymal gland, gives off filaments to it and to the conjunctiva, and pierces the tarsal ligament to be finally distributed to the integument of the upper lid. (*b*) The **frontal** branch runs along the upper wall of the orbit and separates into the supra-trochlear and supra-orbital branches. The former of these leaves the orbit in front and turns up over the bone to supply the integument of the lower forehead; the latter traverses the supra-orbital canal, escapes by the foramen of the same name, and supplies the skin as far back as the occiput as well as the peri-

cranium in the frontal and parietal regions. (*c*) The **nasal** **branch**, crossing to the inner wall of the orbit, enters the anterior ethmoidal foramen, passes thus into the cranium again, runs in a groove on the cribriform plate of the ethmoid and finds exit into the nose through a slit by the side of the crista galli. Here it gives off branches which supply common sensation to the mucous membrane of the fore part of the nose, and then running in a groove on the posterior surface of the nasal bone, it leaves the cavity at the lower border of that bone to supply the integument of the ala and tip of the nose. From the nasal nerve pass fibers to the ophthalmic ganglion and to the ciliary muscle, iris and cornea.

2. The **Superior Maxillary Branch** passes away from the Gasserian ganglion and leaves the cranium by the foramen rotundum. Crossing the spheno-maxillary fossa it enters the orbit through the spheno-maxillary fissure and traverses the infra-orbital canal to emerge upon the face at the infra-orbital foramen. In the *cranium* it gives off a **meningeal** branch to supply the neighboring dura mater. In the *spheno-maxillary fossa* it supplies branches (*a*) to the **integument** over the temporal and post-frontal regions and over the cheeks; (*b*) to the **spheno-palatine ganglion**; (*c*) the **posterior superior dental** branches (generally two), which enter the posterior dental canals in the zygomatic fossa, and, passing forward in the substance of the superior maxilla, give off twigs to the fangs of the molar teeth, supplying them with sensation. In the *infra-orbital canal* the superior maxillary nerve gives off (*a*) the **middle superior dental,** which runs downward and forward in the outer wall of the antrum to reach the roots of the bicuspid teeth; (*b*) the **anterior superior dental,** which likewise runs in the outer wall of the antrum to supply the incisor and canine teeth. After its exit from the infra-orbital canal the nerve divides into **palpebral, nasal** and **labial** branches, which supply sensation to the regions indicated by their names.

3. The **Inferior Maxillary Branch** after its exit from the

cranium is a mixed nerve, supplying motion to the muscles of mastication as well as common sensation to the parts presently to be noted, and special sense to a part of the tongue. Its large or sensory root comes from the Gasserian ganglion to be joined just beneath the base of the skull by the small motor root which has passed under the ganglion. Almost immediately this common trunk divides into (*a*) **anterior** and (*b*) **posterior** branches, but first gives off a *recurrent meningeal* branch and a branch to the *internal pterygoid* muscle.

(*a*) The **anterior** of the two divisions of the inferior maxillary nerve receives nearly the whole of the motor root and divides into branches which supply the muscles of mastication, excepting the internal pterygoid and the buccinator.

(*b*) The **posterior** division, chiefly sensory, divides into the **auriculo-temporal, lingual** and **inferior dental** branches. The **auriculo-temporal** branch runs backward to a point internal to the neck of the condyle of the inferior maxilla, then passing upward under the parotid gland divides into branches, which are distributed to the external auditory meatus, parotid gland, integument of the temporal region and of the ear and surrounding parts. It communicates with the otic ganglion. The **lingual** branch is joined by the *chorda tympani*, passes to the inner side of the ramus of the jaw, crosses Wharton's duct, and is distributed to the papillæ and mucous membrane of the tongue and mouth. It communicates with the facial through the chorda tympani, with the hypoglossal, and with the submaxillary ganglion. The **inferior dental branch** passes between the internal lateral ligament and ramus of the jaw to enter the inferior dental foramen. Thence it traverses the dental canal in the inferior maxilla to issue at the mental foramen. Here it divides into *incisor* and *mental* branches; the former continues in the bone to supply the incisor and canine teeth; the latter supplies the skin of the chin and lower lip. In its course the inferior dental gives off the *mylo-hyoid* (before entering the canal)

to the mylo-hyoid and anterior belly of the digastric, and *dental branches* to supply the molar and bicuspid teeth.

Four small ganglia, usually classed as part of the sympathetic system, are connected with the three divisions of the trifacial nerve. The **ophthalmic,** or **lenticular,** ganglion is connected with the first division; the **spheno-palatine** or **Meckel's** with the second; the **otic** and **submaxillary** with the third. All these receive sensory fibers from the trifacial and motor fibers from various sources.

Functions.—It is seen from the foregoing description that the trifacial is the great sensory nerve of the head and face, and the motor nerve of the muscles of mastication. The small, or motor, division has properly been called the "nerve of mastication." It is insensible upon stimulation before it is joined by the third division of the sensory root. Its section causes *paralysis of the muscles of mastication* on that side. It cannot be doubted that the large root is exclusively sensory at its origin, and the acuteness of that sensibility, as, *e.g.*, in the teeth, is a matter of common observation. Immediate *loss of sensibility* in the area of its distribution follows section, and even the cornea, which is normally exquisitely sensitive, can be touched without exciting pain. Both roots are usually cut at the same time, and besides a loss of motion and general sensibility, section of this nerve produces a decided effect upon the *eye*, the sense of *taste*, *deglutition* and the *nutrition* of the parts to which the nerve is distributed. The flow of tears is increased, the pupil becomes temporarily contracted and the ball protrudes. In a few hours congestion is marked, and in a day or two the cornea sloughs and the eye is destroyed. Section of the fifth before its lingual branch is joined by the chorda tympani from the facial causes a loss of general sensation, but *not of taste,* in the anterior part of the tongue; section of the lingual branch after it has received the chorda is followed by loss of general sensation *and of taste.* This shows that the special sensibility distributed to the tongue by

the lingual branch of the fifth is furnished by the *chorda tympani*. The fifth nerve sends filaments to give sensibility to the *velum palati*. The reflex act of deglutition is due to impressions carried from the velum and neighboring parts to the centers; when the fifth nerve is cut no such impressions are conveyed and the reflex act cannot be excited.

Regarding *nutrition* it is noticed that, besides the sloughing of the cornea, there is also, about the same time, the appearance of ulcers in the mouth and on the tongue, and animals thus experimented upon soon die. These lesions are much less marked when the section is *behind the semilunar ganglion*. Explanations of this difference are not altogether satisfactory, but it is rational to suppose that section of sympathetic fibers when the nerve is cut in front of Gasser's ganglion is responsible for the disturbances of nutrition; for this is the system of nutrition, and changes following its section in other parts of the body are not unlike those under discussion. Why, however, the changes should be *inflammatory* in character is not explained by this hypothesis, unless it be an explanation to say that the inflammation is set up by the impairment of nutrition in these structures—the impairment resulting in part from the impoverished condition of the blood as a consequence of the inability of the animal to chew.

Sixth Nerve (Abducens).

Origin.—This is a motor nerve entirely. Its **apparent origin** is from the lower border of the pons in the groove separating it from the anterior pyramid of the medulla. Its **deep origin** is close to the median line beneath the floor of the fourth ventricle a little below the motor root of the fifth.

Course and Distribution.—The nerve enters the cavernous sinus, runs forward to enter the orbit by the sphenoidal fissure, passes between the two heads of the **external rectus,** and is distributed to the ocular surface of that muscle. In the cavernous

sinus it receives fibers from the first division of the fifth and from the sympathetic.

Function.—The function is indicated in its distribution. It is insensible at its origin. Stimulation produces contraction of the external rectus; section causes paralysis of that muscle and consequent *internal strabismus* and *diplopia.*

Seventh Nerve (Facial).

Origin.—The **apparent origin** of the seventh is from the upper end of the medulla in the groove between the olivary and restiform bodies. Its **deep origin** is in the pons beneath the floor of the fourth ventricle a little external to the nucleus of the sixth.

Course and Distribution.—The seventh nerve passes outward and forward with the auditory nerve (on its inner side) to enter the internal auditory meatus. From their relative firmness and texture and their close relation here, the seventh and eighth nerves have been called respectively the **portio dura** and the **portio mollis.** Running between them is a fasciculus from the medulla known as the **intermediary nerve of Wrisberg,** or the **portio inter duram et mollem;** most of its fibers join the facial in the internal auditory meatus. The facial nerve enters the Fallopian aqueduct at the bottom of the meatus and follows it to issue at the stylo-mastoid foramen, run forward in the substance of the parotid gland and divide behind the ramus of the jaw into *temporo-facial* and *cervico-facial* branches.

Its branches of communication are numerous. (1) In the *internal auditory meatus* it communicates with the auditory nerve; (2) in the *aqueductus Fallopii* with the otic and spheno-palatine ganglia, with the sympathetic and with the auricular branch of the pneumogastric; (3) after leaving the *stylo-mastoid foramen,* with the fifth, ninth, tenth and sympathetic.

Its branches of distribution are also quite numerous. (1) In the *aqueductus Fallopii* it gives off (*a*) the **tympanic** branch to

the stapedius muscle, and (*b*) the **chorda tympani,** which passes through the cavity of the tympanum and emerges by a foramen at the inner end of the Glaserian fissure to go to the lingual branch of the fifth. (2) At its *exit from the stylo-mastoid foramen* it gives off (*a*) a **posterior auricular** branch which, receiving a filament from the auricular branch of the tenth, is distributed to the retrahens aurem and the occipital portion of the occipito-frontalis; (*b*) a **digastric** branch to the posterior belly of the digastric muscle; (*c*) a **stylo-hyoid** branch to the muscle of that name. (3) *On the face* it divides into (*a*) a **temporo-facial** branch, which is distributed to the muscles over the temple and upper face; and (*b*) a **cervico-facial** branch, which is distributed to the lower face and upper cervical region.

Functions.—This is the motor nerve of the muscles of expression, of the platysma, buccinator, digastric (posterior belly), stylo-hyoid, the muscles of the external ear and the stapedius. Communicating freely with the fifth, it also contains sensory fibers, but it is in all probability insensible at its root. Its section causes paralysis of the muscles which it supplies, but no marked changes in sensation. The branches to the otic and spheno-palatine ganglia in the aqueductus Fallopii constitute their motor roots; the branch given off in this situation to the tenth supplies it with motor filaments, and probably also here pass sensory fibers from the tenth to the seventh. In facial paralysis when the lesion is in the aqueductus Fallopii or behind it, there is paralysis also of the muscles of the palate and uvula, the uvula is drawn to the opposite side and there is trouble in deglutition. The fibers to the azygos uvulæ and levator palati pass from the aqueductus Fallopii through Meckel's ganglion.

The effect of paralysis of the facial upon the superficial muscles of the face is suggested in its distribution. The brow cannot be corrugated; the eye is constantly open and there may be consequent inflammation from exposure; the nostril cannot be dilated, and inspiration and possibly olfaction are interfered with;

the cheek is flaccid; the lips are immobile and saliva may flow from that corner of the mouth; the buccinator is paralyzed, and there is often great difficulty in mastication because of the accumulation of food between the cheek and the teeth; the unopposed action of the muscles of the opposite side greatly distort the facial features, the affected side being quite expressionless. Facial monoplegia is common; facial diplegia is very uncommon.

The Chorda Tympani.—This branch of the seventh is concerned especially in *gustation*. The fibers of which it is composed undoubtedly come from the nerve of Wrisberg. Section of the seventh involving also the nerve of Wrisberg causes not only facial palsy but also a loss of the sense of taste in the anterior two-thirds of the tongue. The sense of taste will receive later notice.

Eighth Nerve (Auditory).

Origin.—This is a nerve of special sense. Its **apparent origin** is by two roots—one from the groove between the olivary and restiform bodies at the lower border of the pons, the other coming around the upper end of the restiform body to join the first in the groove. The **deep origin** of the two roots is different. That of the median root is the dorsal auditory nucleus in the floor of the fourth ventricle; that of the lateral root is mainly from the ventral auditory nucleus in front of the restiform body between the two roots.

Course and Distribution.—Crossing the posterior border of the middle peduncle of the cerebellum, it enters the internal auditory meatus in company with the facial nerve and the nerve of Wrisberg. At the bottom of the meatus it receives fibers from the seventh, and divides into branches which pass to the cochlea, semicircular canals and vestibule.

Function.—This nerve receives and conveys to the brain impressions produced by sound waves; it is the nerve of *hearing*

and is in all probability not sensible to stimulation in any other way.

Ninth Nerve (Glosso-pharyngeal).

Origin.—The **apparent origin** of this nerve is from the upper part of the medulla in the groove between the olivary and restiform bodies. Its **deep origin** is in the lower part of the floor of the fourth ventricle above the nucleus of the tenth.

Course and Distribution.—Leaving the skull by the jugular foramen, it passes forward between the internal jugular vein and the internal carotid artery, descends in front of the latter to the lower border of the stylo-pharyngeus where it curves inward, runs beneath the hyoglossus, and is distributed to the fauces, posterior third of the tongue, and the tonsil.

It communicates with the seventh, tenth and sympathetic.

Its branches of distribution go to the mucous membrane and muscles of the pharynx, the stylo-pharyngeus, the tonsil and soft palate, the circumvallate papillæ and the mucous membrane at the base and side of the tongue and on the anterior surface of the epiglottis. Some of its branches join branches from the pharyngeal and external laryngeal branches of the pneumogastric to form the pharyngeal plexus.

Functions.—It is the nerve of sensation to the pharynx and fauces and a nerve of taste to the base of the tongue. Its sensibility at its root is dull, but stimulation produces no motion. Although this nerve is distributed to the mucous membrane over the base of the tongue, palate and pharynx, these parts receive the greater portion of their general sensibility from filaments of the fifth, and section of the ninth produces no marked effect upon the reflex phenomena of deglutition. The sense of taste is distributed to the anterior two-thirds of the tongue by the chorda tympani, and it has nothing to do with general sensation, while the glosso-pharyngeal, endowing the posterior third with gustatory power, also furnishes to it a degree of general sensibility.

Tenth Nerve (Pneumogastric, Vagus).

Origin.—This is a mixed nerve. Its **apparent origin** is from the groove between the olivary and restiform bodies below the ninth. Its **deep origin** is in the floor of the fourth ventricle just below that of the glasso-pharyngeal.

Course and Distribution.—As it leaves the cranium by the jugular foramen it presents a ganglionic enlargement, the **jugular ganglion,** or **ganglion of the root,** just below which it is joined by the accessory portion of the spinal accessory. Below the junction is a second ganglion, the **ganglion of the trunk.** The accessory part of the eleventh passes through this ganglion, and below unites with the vagus trunk to pass chiefly into its pharyngeal and superior laryngeal branches. The pneumogastric passes down the neck behind and between the internal jugular vein and the internal and common carotid arteries, and sends motor and sensory fibers to the organs of voice and respiration, and motor fibers to the pharynx, esophagus, stomach and heart.

The branches of the pneumogastric are numerous. (1) *In the jugular fossa* it gives off (*a*) a **meningeal** branch to the dura mater of the posterior fossa of the skull; (*b*) an **auricular** branch which, traversing the substance of the temporal bone, emerges by the auricular fissure to supply the integument of the back part of the pinna and external auditory meatus. (2) *In the neck* it gives off (*a*) a **pharyngeal** branch, which consists mainly of fibers from the accessory portion of the eleventh and is the chief motor nerve of the pharynx and soft palate; (*b*) a **superior laryngeal** branch, which also consists mainly of fibers from the accessory part of the eleventh and is the chief sensory nerve of the larynx; it also animates the crico-thyroid muscle; (*c*) a **recurrent laryngeal** branch, which, on the right side, winds round the subclavian artery, and, on the left, round the aorta to return to the muscles of the larynx whose motor nerve it is; (*d*) **cervical cardiac** branches, which communicate with the cardiac

branches of the sympathetic and pass to the deep cardiac plexus. (3) *In the thorax* it gives off (*a*) **thoracic cardiac** branches, which pass to the deep cardiac plexus; (*b*) **anterior pulmonary** branches, which go to the roots of the lungs in front; (*c*) **posterior pulmonary** branches, which go to the roots of the lungs behind and send some filaments to the pericardium; filaments from (*b*) and (*c*) follow the air passages through the lungs; (*d*) **esophageal** branches, which unite with fibers from the opposite nerve to form the esophageal plexus. (4) *In the abdomen* are the **gastric branches**; those from the left nerve are distributed to the anterior surface of the stomach, and those from the right to the posterior; the right vagus is also distributed to the liver, spleen, kidneys and entire small intestine.

Throughout the whole course of the pneumogastric communication with other nerves, especially the sympathetic, is very free.

Functions.—The root of the tenth in the medulla is purely sensory, but the nerve communicates with at least five motor nerves, and is distributed to mucous membranes and to voluntary and involuntary muscle tissue. The **auricular** branches contain both motor and sensory fibers, and their function is indicated in their distribution. The **pharyngeal** branches are mixed, receiving motor filaments from the spinal accessory. Sensibility is supplied to the pharynx not by this nerve alone, but by the branches of the fifth and probably of the ninth; indeed it seems that the pharyngeal branches of the tenth have little to do with the reflex phenomena of deglutition. The **superior laryngeal** branches, mainly sensory, supply also motor power to the crico-thyroids. Stimulation of the filaments of these branches prevents the entrance of foreign bodies into the larynx by reflex closure of the glottis, and also excites movements of deglutition. Their section produces hoarseness. The **recurrent,** or **inferior laryngeal,** branches, chiefly motor, supply the muscular tissue of the upper esophagus and trachea, as well as the muscles of the larynx. Section of them causes embarrassed phonation, though

the fibers thus influencing the vocal sounds come to the recurrent laryngeal from the spinal accessary. The uses of the **cardiac** branches have been noticed under discussion of the heart's action. The **pulmonary** branches are both motor and sensory and go to the lower trachea, the bronchi and lung substance. Section of the tenth destroys the sensibility of the mucous membrane of the trachea and bronchi and the contractile power of the muscular fibers of the tubes. The **esophageal** branches are mixed, though motor fibers predominate. Food will not pass readily into the stomach on section of the tenth because of the absence of muscular contractions in the esophagus.

Influence of the Vagus on Respiration.—Section of both these nerves temporarily increases the number of respirations, which soon, however, become exceedingly slow until death ensues. Inspiration is very profound—indeed so profound as to produce rupture of some of the pulmonary capillaries with consequent hemorrhage and coagulation of the blood and consolidation of the lung in part or whole. Section of only one of the vagi is not usually followed by death. Further notice of the relation of the pneumogastric to respiration is given elsewhere.

Influence of Vagus on the Stomach, Intestine and Liver.—Stimulation of the pneumogastric causes contraction of the stomach; but since the contraction is not immediate, the impulse is probably carried to it by fibers of the sympathetic running with the gastric branches of the tenth. When the vagus is cut during digestion in the stomach the contractions of the muscular wall are impaired and the sensibility of the organ is abolished. Secretion is interfered with, but not stopped.

Section of the vagus seems also to impair **intestinal secretion** and movements, but it is not improbable that this is because sympathetic fibers joining the vagus high in the neck are distributed with it to the intestine.

Simple division of the pneumogastrics inhibits the formation of **glycogen** in the liver; but when the central ends of the cut

nerves are stimulated there is an increased production of sugar even to the point of glycosuria. The irritation is probably reflected through the sympathetic; indeed it is not supposed that the vagi are concerned in the glycogenic function of the liver, except reflexly; its section only prevents the conduction cephalad of the impressions which usually give rise to a secretion of glycogen.

The connection of the vagus with the **kidneys, spleen** and **suprarenal capsules** is obscure.

Eleventh Nerve (Spinal Accessory).

Origin.—This nerve consists of a **cranial** portion, accessory to the tenth, and a **spinal** portion. The **apparent origin** of the cranial root is from the side of the medulla just below the vagus. Its **deep origin** is in the medulla to the posterior and outer side of the nucleus of the ninth. The **apparent origin** of the spinal portion is by several filaments from the side of the cord as low down as the sixth cervical nerve. Its **deep origin** is from a column of cells in the anterior cornu of gray matter of the cord.

Course and Distribution (*Accessory Portion*).—Passing out to the jugular foramen it is joined by the spinal portion, and sends a few filaments to the ganglion of the root of the tenth; then leaving the spinal portion it finds exit from the cranium by the jugular foramen, passes over the ganglion of the trunk of the tenth (adherent to it), and is continued chiefly in the pharyngeal and superior laryngeal branches of that nerve (Gray), but in the recurrent laryngeal as well.

Spinal Portion.—Running upward between the two roots of the spinal nerves the spinal portion enters the cranial cavity by the foramen magnum, passes outward to the jugular foramen, where it joins the accessory portion to separate from it on passing through that foramen. After leaving the skull it takes a course backward, pierces the sterno-mastoid, crosses the occipital triangle and terminates in the trapezius. It gives branches to the sterno-mastoid and to the cervical plexus.

Functions.—Both roots of this nerve are purely motor, but communication with other nerves gives it a degree of sensibility. The fibers from the medulla (accessory) go exclusively to the muscles of the **larynx** and **pharynx,** which those from the cord (spinal) go exclusively to the **sterno-mastoid** and **trapezius**; and section of either root separately is followed by phenomena corresponding to these facts. When both roots are divided there is loss of voice, disturbance of deglutition, loss of cardiac inhibition and partial paralysis of the sterno-mastoid and trapezius. The loss of voice and disturbance in deglutition are explained by the distribution of the fibers of the eleventh with the pharyngeal and laryngeal branches of the tenth. The loss of the power of the vagus to inhibit cardiac action is because the fibers of the tenth which convey the inhibitory impulses are received from the spinal accessory. The sterno-mastoid and trapezius are only partially paralyzed because they receive motor fibers also from the cervical plexus.

Twelfth Nerve (Hypoglossal).

Origin.—This nerve supplies motion to the tongue. Its **apparent origin** is by 10–15 filaments in the groove between the anterior pyramid of the medulla and the olivary body. Its **deep origin** is in the floor of the fourth ventricle under the lower border of the fasciculus teres.

Course and Distribution.—The nerve passes through the anterior condyloid foramen in two bundles which unite to form a common trunk below. Running downward in company with the internal carotid artery and internal jugular vein, it reaches a point opposite the angle of the jaw, then runs forward, crosses the external carotid, lies on the hyoglossus and is continued forward in the genio-hyoglossus to the tip of the tongue.

It communicates with the tenth, sympathetic, first and second cervical and the lingual branch of the fifth.

Its branches of distribution are (1) **meningeal** to the dura

mater in the posterior fossa of the skull; (2) **descendens hypoglossi,** which, running downward across the sheath of the great vessels, meets branches of the second and third cervical nerves to form a loop from which are supplied the sterno-hyoid, the omo-hyoid and the sterno-thyroid muscles; (3) **thyro-hyoid** to the muscle of that name; (4) **muscular** to the muscular substances of the tongue and to the styloglossus, hyoglossus, genio-hyoid and genio-hyoglossus muscles.

Functions.—This nerve possesses no sensibility at its root, but receives sensory fibers from anastomoses with other nerves. Its stimulation, therefore, causes movements of the tongue and some pain. Section of both nerves causes difficult deglutition, loss of power over the tongue and consequent disturbances in mastication and articulation. When the twelfth is affected in hemiplegia the tongue, on protrusion, deviates to the affected side because it is *pushed* out by the genio-hyoglossus.

It will be seen from the foregoing that, classified according to their properties at their roots, the I., II. and VIII. are nerves of special sense; the III., IV., VI., XI. and XII. are motor; the X. is sensory; and the V., VII. and IX. are mixed. It is to be remembered, however, that most of these (excepting the nerves of special sense) are mixed in their *distribution* by reason of the reception of fibers from other nerves. The term "mixed" in the above classification is used as meaning the association of special sensory fibers with motor or common sensory fibers as well as the association of these latter with each other. The VII. is classed as a mixed nerve only by allowing that the intermediary nerve of Wrisberg is to be considered a part of it. Its own proper root is purely motor.

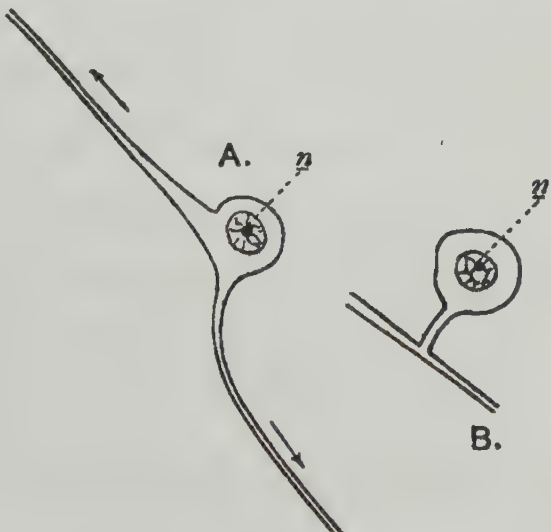
THE SPINAL NERVES.

The spinal nerves, thirty-one on each side, are so called from the fact that they originate in the spinal cord and escape from the spinal canal by the intervertebral foramina. Eight pairs come

from the cervical region of the column, twelve from the dorsal, five from the lumbar, five from the sacral, and one from the coccygeal. They are numbered according to their foramina of exit.

Each nerve rises by two roots—an **anterior** which can be traced to the anterior cornu of gray matter and a **posterior** which goes (apparently) to the posterior cornu—and these emerge re-

FIG. 83.



A, bipolar cell from spinal ganglion of a 4½ weeks' embryo (after *His*). *n*, nucleus; the arrows indicate the direction in which the nerve processes grow, one to the spinal cord, the other to the periphery. B, a cell from the spinal ganglion of the adult; the two processes have coalesced to form a T-shaped junction. (*Kirkes.*)

spectively from the antero-lateral and postero-lateral fissures of the cord. Before leaving the spinal canal these two roots join to pass through the corresponding intervertebral foramen as a single trunk which, however, just beyond that foramen divides into anterior and posterior branches to be distributed to the anterior and posterior parts of the body.

The posterior root (inside the spinal canal) is **sensory,** and has a ganglion developed upon it. The fibers of the posterior

root are outgrowths of cells in the ganglion of that root, as indicated in Fig. 83. This accounts for the *arborization* of the different fibers around cells in the cord instead of an actual *connection* with them. These facts should not be lost sight of though it is customary to speak of an efferent fiber as passing directly to a cord cell itself. The anterior root is entirely **motor** except for a degree of "recurrent" sensibility which is due to the presence in it of posterior root fibers which have passed backward from the point of junction of the two probably to supply the membranes of the cord. The common trunk is, of course, mixed, as are the anterior and posterior branches passing from it.

These spinal nerves are distributed to the muscles of the trunk and extremities, to the integument of almost the entire body and to some mucous membranes; and from what has been said in speaking of the cord about the connection between it and these nerves, and their connection through it with the higher centers, it is evident that they are most important factors which, acting under the guidance of the sensorium, on the one hand, tell of the condition of the organism—its relations and environments—and, on the other, control the voluntary movements of the body.

The spinal nerve fibers come in part directly from the brain and in part from the gray cells of the cord.

THE SYMPATHETIC SYSTEM.

The sympathetic has been separated from the cerebro-spinal system only for the sake of convenience. The former sends filaments to the latter and receives both motor and sensory fibers in return, while the coöperation of the two systems, regulating in harmony all the physiological processes going on in the body, is too evident to be questioned.

The sympathetic system is remarkable for the number of ganglia connected with it. These may be divided into (*a*) those along the vertebral column, as the thoracic, (*b*) those in close

proximity to the viscera and from which those viscera are to be directly supplied, as the semilunar, and (*c*) terminal ganglia which the fibers reach just before final distribution, as the cardiac, intestinal, etc. The sympathetic is, therefore, frequently known as the **ganglionic** system.

Arrangement.—There is on each side of the spinal column, extending from the lenticular ganglion above to the ganglion impar below, a **chain of ganglia** all of which are united to each other and to the ganglia of the opposite chain by commissural fibers. From these ganglia go fibers to form numerous plexuses and to be distributed to the various parts. In the skull there are four of these ganglia, the otic, ophthalmic, submaxillary and spheno-palatine or Meckel's; in the cervical region there are three; in the dorsal twelve; in the lumbar four; in the sacral four or five; and in front of the coccyx the single ganglion impar.

Connections between the cranial nerves and **cranial** sympathetic ganglia have already been noted.

The **cervical** ganglia are of special interest as furnishing the chief sympathetic supply to the heart.

The **thoracic** or dorsal ganglia give rise to the sympathetic supply for the great abdominal viscera. From the sixth, seventh, eighth and ninth springs the **great splanchnic nerve,** which passes through the diaphragm to the **semilunar** ganglion. This is the largest of the sympathetic ganglion, and is sometimes called the abdominal brain. It has been inaccurately called the center of the sympathetic system. The two ganglia occupy positions on opposite sides of the celiac axis, and give rise to fibers which supply most of the abdominal viscera. The tenth and eleventh thoracic ganglia give rise to the **lesser splanchnic nerve.** From the last thoracic springs the **renal splanchnic nerve.** The radiating fibers from the semilunar ganglia form the *solar plexuses* for the two sides.

The **lumbar** ganglia give off fibers to form the aortic lumbar and hypogastric plexuses.

The **sacral** and **coccygeal** ganglia supply the pelvic vessels.

Properties.—The ganglia and nerves are slightly sensitive. Contraction of involuntary muscular tissue follows stimulation—not immediately, but after a considerable interval, and the subsequent relaxation is tardy. Some of the ganglia are dependent for power upon their fibers from the cerebro-spinal system, while others seem capable of acting independently, at least for a time.

Functions.—Little is known of the functions of the sympathetic except as regards efferent fibers. They are distributed in general to the non-striped musculature of the circulatory apparatus and of the viscera, to secreting glands and to the heart. The heart furnishes the only example of a direct sympathetic supply to striated muscle. The sympathetic has a very definite effect upon *secretion*, *nutrition* and the local production of *heat*. Section of the sympathetic fibers going to any part causes hyperemia, an increased amount of secretion (sweat, *e. g.*), and a rise of temperature in that part. The last two conditions are caused by the first, and it in turn is due to a paralysis of the muscular coat of the vessels, allowing an abrogation of their usual tonic condition and, consequently, dilatation and an increased amount of blood with exaggerated nutritive activity. This statement confronts us with the question of vaso-motor action.

Vaso-motor Phenomena.—By **vaso-motor** nerves is meant those fibers which convey to the muscular coat of the vessel walls impulses causing them to contract and decrease the caliber, or to relax and increase it. Those causing contraction are called **vaso-constrictors**; those causing relaxation **vaso-dilators.** It is mainly through the operation of vaso-motor nerves that the sympathetic system influences nutrition *in a particular part*, though all vaso-motor fibers are not confined to the sympathetic cords. However, it is not through the operation of the vaso-motor nerves alone that the sympathetic lays claim to be the "system of nutrition," for all the parts to which its other fibers are distributed contribute also very materially to nutrition, though

perhaps in not so direct a manner as do the muscular coats of the arteries. While intestinal peristalsis, the secretion of many glands, as, for example, the production of glycogen, bile, etc., cannot be shown to be absolutely dependent on sympathetic connections, yet all these processes—nutritive in nature—have their normal activity seriously impaired by withdrawal of the sympathetic influence.

The chief vaso-motor **center** is in the medulla, though accessory centers exist also in the cord; all vaso-motor fibers pass out from these centers and leave the cerebro-spinal axis with the cranial or spinal nerves.

The most usual mode of action of the vaso-motor nerves is *reflex*, as when the mucous membrane of the stomach becomes hyperemic upon the introduction of food; or when the salivary secretion increases during mastication, or even sometimes at the sight or thought of food; or when emotions are evidenced by paling or blushing.

Raising blood-pressure by stimulating the vaso-constrictors and lowering it by stimulating the vaso-dilators are simply mechanical results, and require no comment. For other remarks upon vaso-motor nerves see p. 84.

Sleep.—Sleep is closely associated with vaso-motor action. Every part of the body has a function to perform, but it must have some rest from that performance or it will begin to act inefficiently and finally cease altogether. For most organs these periods of rest occur at approximately uniform intervals, as in case of the stomach, heart or respiratory muscles; but notably in case of the involuntary muscles these periods of repose have no regularity—*i. e.*, a person exercises them at no regular time except by accident of occupation or otherwise. But, in any case, there comes a time when repose must be had, for during activity the destructive processes far exceed the constructive, and in order for the balance to be preserved there must be a time when the opposite is true.

Now we may say that it is the function of the brain to furnish consciousness—if we can allow that consciousness embraces all the various manifestations of nerve force peculiar to the brain. For the brain to suspend this function at frequent intervals like the heart (*e. g.*) would be manifestly impossible if one is to do any consecutive work depending upon this organ. The brain works longer, and must, therefore, rest longer at a time than most of the other organs of the body. True, so far as the voluntary muscles are concerned they rest best probably when the brain is resting, but the latter condition is not a necessary one for the maintenance of their physiological integrity. This repose of the brain—this temporary abolition of the cerebral functions—is **sleep.** While, of course, the activity of that organ during wakefulness may be increased or diminished by volition, and it may, therefore rest from a comparative standpoint—as when one ceases to think actively upon a subject and becomes mentally listless—still the brain can never, under such circumstances, rest properly, and sleep finally becomes imperative.

Vascular Phenomena of Sleep.—Coma is analogous to sleep in that consciousness is lost; but in this case the brain is *congested* and the condition is unnatural. It was long supposed that this was the vascular condition during natural sleep, but application of the physiological principles prevailing in other parts of the body would rather presuppose a condition of cerebral *anemia;* for the brain receives blood for two purposes—first, to supply nutrition to the nervous substance, and second, to bring supplies which, by the action of the brain cells, may be converted into nerve force—and during sleep only the first of these purposes is to be served. This is true in case of glands, muscles, etc., during their intervals of repose. As a matter of fact, the cerebral vessels are *contracted* and there is much less blood in the brain during sleep than during consciousness.

Dreams.—In explanation of the phenomena of dreams and somnambulism, it is said that what we call sleep may occur in

one part of the brain and not in another, or in different degrees in different parts of the nervous centers. "In the former case [dreams] the cerebrum is still partially active; but the mind products of its action are no longer corrected by the reception, on the part of the sleeping *sensorium*, of impressions of objects belonging to the outer world; neither can the cerebrum, in this half-awake condition, act on the centers of reflex action of the voluntary muscles, so as to cause the latter to contract—a fact within the painful experience of all who have suffered from nightmare. In somnambulism the cerebrum is capable of exciting that train of reflex nervous action which is necessary for progression, while the nerve center of *muscular sense* (in the cerebellum?) is presumably fully awake; but the *sensorium* is still asleep, and impressions made on it are not sufficiently *felt* to rouse the cerebrum to a comparison of the difference between mere ideas or memories and sensations derived from external objects" (Kirkes).

Relation Between the Cerebro-spinal and Sympathetic Systems.—A brief résumé may help to clarify the association between the two systems.

1. *Anatomically.*—The two are developed from the same embryological tissue; the vaso-motor sympathetic fibers obey centers in the medulla and cord, and must, therefore, be connected with those centers either directly or indirectly; characteristic small medullated fibers pass at intervals from the cord through the roots into the sympathetic ganglia; they send fibers each to the trunks of the other to be distributed directly, or to form plexuses and then be distributed together; their fibers are found together in all organs which receive cerebro-spinal nerves (unless they be non-vascular); in some of these organs just named the sympathetic fibers are there only as vaso-motor nerves, while in others, as glandular structures like the liver and salivary glands, sympathetic fibers are distributed to the gland cells themselves, and both have a definite but associated influence on secretion.

2. *Physiologically.*—The physiological relation is best indicated by examples. A great many, if not all, the sympathetic ganglia seem to receive their power to generate nerve force from the cerebro-spinal system; there can be no proper nutrition of the parts animated by cerebro-spinal fibers without the associated action of vaso-motor sympathetic fibers—not even of the nerve cells and fibers themselves; in reflex action the afferent impression may be conveyed by a cerebro-spinal fiber and reflected through a sympathetic, or vice versa; when one hand is thrust into hot or cold water the temperature of the opposite hand may be raised or lowered, impressions having been carried to the center by cerebro-spinal and reflected by sympathetic fibers, not only to the immersed hand, but to the other as well; food is taken into the mouth, impressions are carried by nerves of common sensation to the brain and are reflected through the sympathetic system, an increased amount of blood is thereby sent to the salivary glands and an increased secretion supervenes; one smells savory articles and the mouth waters, etc.

Examples could be multiplied *ad infinitum* to establish the coöperation existing between the two systems. What has been incidentally and indirectly said on this point in considering secretion, digestion, circulation, respiration, etc., serves to emphasize their connection.

CHAPTER XI.

THE SENSES.

IT is evident from preceding remarks that it is through the intervention of the nervous system that we have a "sense" of existence, of the existence and condition of different parts of our bodies and of our relations to the external world. The knowledge we thus obtain is based upon sensations of various kinds, all of which are carried to the centers by afferent fibers. Such sensations may be what are termed (*A*) **Common,** or (*B*) **Special,** including (1) *Touch*, (2) *Smell*, (3) *Sight*, (4) *Taste*, (5) *Hearing*. It is to be remembered that the seat of sensation is in the brain, and not in any organ which primarily receives or conveys the impression. We do not in reality see with the eye or hear with the ear; these are only complex organs so arranged that rays of light or sound waves produce upon them such impressions as, when transmitted to the sensorium, will give rise to the sensations of sight or hearing.

(A) COMMON SENSATIONS.

As regards the uses of the fibers conveying impressions which result in these sensations, they (unless it be those concerned with tactile impressions) are distinct from those of special sense. That is to say, the fibers of the olfactory, optic, gustatory and auditory nerves do not convey general impressions; but it is almost certain that fibers conveying tactile impressions convey also painful impressions—and the sensation of pain is taken as typical of common sensations. It is known that very painful impressions sometimes overcome tactile sensibility, and that

very frequently tactile sensibility remains in parts which receive no painful impressions, as, *e. g.*, under anesthesia by cocain; but it may be that the power in the same fiber to convey, in the first case tactile, and in the second painful impressions is destroyed without destroying its power to convey the other.

The varieties of common sensation are too numerous to even mention. Thirst, hunger, fatigue, discomfort, satiety, etc., are everyday examples, as are also the desire to urinate or defecate. Numerous subdivisions of the sensation of pain might be mentioned, such as itching, burning, aching, etc. The so-called muscular sense—by which we become aware of the condition, relation, coördination and degree of activity or repose of the muscles—will be considered as belonging here.

(B) SPECIAL SENSATIONS.

1. The Sense of Touch.

The sense of touch is closely related to common sensation. Its distribution over the body is as uniform as that of common sensation, but it is most highly developed in those parts where general sensibility is most marked (as in the skin), and attains its highest degree of perfection only in those situations in which tactile corpuscles exist, for example, on the palmar surfaces of the tips of the fingers. The teeth, hair, nails, etc., are rather surprisingly endowed with tactile sensibility. Leaving pain and the muscular sense as part of general sensibility, the sense of touch may be considered under two heads—(*a*) **Tactile Sensibility** proper and (*b*) **Temperature.**

(*a*) **Tactile sensibility** proper is most marked where the epidermis over the papillæ is thin. When the epidermis is removed and the cutis is touched there is pain instead. Tactile sensibility is much decreased where the epidermis is thickened, as over the heel. The terminal tactile organs have been described in connection with afferent nerves. They are chiefly

the **end bulbs of Krause** and the **tactile corpuscles of Meissner.** (See Figs. 67 and 68.) Besides, tactile impressions are received by the free extremities of **afferent nerves** situated over the body at large. Numbness from cold is due to interference with cutaneous circulation—upon which the sense of touch is directly dependent. It is almost impossible to distinguish mere touch from pressure.

Acuteness.—How the sense of touch is capable of development by practice is well illustrated in the case of many blind persons. They learn to read with comparative facility by passing the hand over raised letters; or they frequently make the sense of touch take the place of the lost sense in other almost incredible ways. The acuteness of this sense in different portions of the body has been made the subject of observation by touching two different parts in the same region with finely pointed instruments and noting how near the points can be brought together and still be recognized as *two*. This distance is found to vary from $\frac{1}{24}$ inch on the tip of the tongue to $2\frac{1}{2}$ inches in the dorsal region.

(*b*) It is not improbable that there are special nerve endings concerned in the reception of **temperature** impressions, though this has not been definitely proven. Decisions as to temperature are only relative; the surface temperature of the part upon which the impression is made is the standard, and one can only tell absolutely whether the object is hotter or colder than the skin, and, within certain limits, approximate how much hotter or colder. The delicacy of the temperature sense agrees with that of touch as regards the thickness or absence of the epidermis.

2. The Sense of Smell.

Regarding the mechanism of olfaction it is found that one of the first conditions necessary is the presence of particular cells. Between the epithelial cells of the mucous membrane to which

the olfactory fibers are distributed are delicate spindle-shaped cells known as **olfactory cells,** and to them pass the terminal filaments from the olfactory bulbs. These cells are stimulated by contact with odorous substances, and from them go, by way of the nerve fibers, impressions which are recognized as *odors* of different kinds. The olfactory fibers are the only ones which will convey such impressions. True, the same substance may, at the same time, excite other sensations, as of pain or taste, but the impressions giving rise to these latter sensations are conveyed by different fibers altogether. The substances which excite olfaction must come in *actual contact* with the nerve terminals and to do this must be dissolved in the mucus of the nasal mucous membrane; hence dryness of the nasal cavities (as in the first stage of nasal catarrh) interferes with olfaction. It is also said that odorous substances introduced in solution into the nasal cavities will not excite the sense of smell, but that they must be introduced by a current of air.

Whether an odor is pleasant or unpleasant is largely a relative matter ; odors most disgusting to some animals are not offensive to others. This same difference may also hold good among different men. Impairment of the sense of taste, for some reason, follows a loss of the sense of smell.

3. The Sense of Sight.

It is not intended to go into a detailed consideration of the sense of sight, but some remarks on the normal eye and its action are in order.

Protection of the Ball.—The orbital cavity has a pyramidal shape with its base forward. It contains the eye-ball, its muscles, some adipose tissue and most of the lachrymal apparatus. Above the orbit, the eye-brows prevent a flow of perspiration from the forehead on to the lid, and also shade the eye to some extent. The lids, when closed, entirely obscure the balls and protect them in front. On their free borders are rows of hairs

(eye-lashes) curling away from the globe and shading and protecting it from dust. The lids are closed by the *orbiculares palpebrarum* and opened by the *levatores palpebrarum superiores.* In the ordinary closing of the lids only the upper one is moved, but the lower one is raised in forcible contraction of the orbicularis. Intervention of the will is not necessary to the action of these muscles, though they are striated. Except during fatigue, the eyes are kept open involuntarily, but when the cornea is touched no effort of the will can prevent contraction of the orbicularis palpebrarum. During sleep the globes are rotated upward.

The Lachrymal Apparatus.—This consists of the **lachrymal glands, canal, duct** and **sac,** and the **nasal duct.** The secretion of the **lachrymal gland** keeps the cornea and conjunctiva constantly bathed in a thin fluid. It is situated in the orbital cavity at its upper and outer portion. Its secretion is discharged upon the conjunctiva by several little ducts. The excess of secretion is carried into the nose through the nasal duct. Near the inner canthus is a small opening in each lid; these openings are the orifices of the lachrymal canals, which canals join at the inner angle of the eye to form the **lachrymal sac**; the sac is continued below as the **nasal duct,** opening into the inferior meatus of the nose. The secretion of tears is much diminished during sleep. The influence of the nervous system on lachrymal secretion is well known. Emotional disturbances operate through the sympathetic to increase the flow. Irritation of the mucous membrane of the nose or eye is followed by a like result.

Movements of the Ball.—The **capsule of Tenon,** a fibrous membrane outside the sclerotic, holds the ball loosely in place. A small amount of adipose tissue behind the globe is never absent. Movements of the ball are effected through the action of the **internal** and **external recti,** the **superior** and **inferior recti,** and the **superior** and **inferior oblique**; of these, all but the two last named arise from the apex of the orbital cavity. The recti are inserted into the sclerotic just back of the cornea.

The superior oblique runs along the inner aspect of the orbital cavity to a point near the supero-internal angle; here it becomes tendinous, passes through a fibro-cartilaginous ring, and then turns backward and outward to be inserted into the sclerotic between the superior and external recti just behind the center of the globe. The inferior oblique arises just within the orbital

FIG. 84.

Lateral view of the muscles of the eye-ball.

5, trochlea or pulley of the superior oblique muscle, 12; 6, optic nerve; 8, superior, 9, inferior, and 12, external rectus; 13, inferior oblique. (*Landois.*)

cavity near the anterior inferior angle, and passes around the anterior part of the globe to be inserted in the sclerotic just below the superior oblique.

The effect these muscles have upon the movements of the ball is indicated by their origin and attachment. The external and internal recti rotate it outward and inward, the superior and inferior recti upward and downward. The superior and inferior

oblique antagonize each other. The former rotates the globe so that the pupil is directed outward and downward; the latter so that it looks outward and upward. The associated action of all these muscles can produce almost any variety of movements, and no effort of the will is necessary to properly associate them when it is desired to direct the line of vision toward a certain object. For instance, when it is desired to look at an object on the right it takes no distinct voluntary effort to contract the external rectus of the right eye and the internal rectus of the left. It will be seen later that vision for the two eyes is normal only when impressions are made upon exactly corresponding parts of the two retinæ, so that they may act as a single organ; and for this to be done not always the same movements are called for in both balls.

Anatomy of the Ball.—The eye-ball is a globular body consisting of several coats enclosing refracting media. Of these coats the external is the **sclerotic,** dense and fibrous, covering the posterior five-sixths of the organ and continuous with the **cornea,** which covers the anterior one-sixth. It is not well supplied with blood-vessels. The cornea is transparent, and upon its external surface are several layers of delicate nucleated epithelium; underneath this layer of cells is a thin membrane, the **anterior elastic lamella,** which is a continuation of the **conjunctiva.** The substance proper of the cornea is composed of pale interlacing fibers among which are connective tissue corpuscles and quite a quantity of fluid. These fibers are continuous from the sclerotic, but they lose their opacity at the corneo-sclerotic margin. On the posterior surface of the cornea is the transparent elastic **membrane of Descemet,** a part of which, at the circumference of the iris, passes into the ciliary muscle. The cornea is very sensitive, but contains no blood-vessels.

Next inside the sclerotic is the **choroid** coat of the eye. It does not lie under the cornea, but is confined to the sclerotic area of the ball. Behind the optic nerve penetrates it, and in front it is connected with the **iris.** The choroid is very vascular.

Its color is dark brown on account of the abundance of pigment in the cells on the inner surface of the membrane. Anteriorly the choroid is folded in upon itself to form the **ciliary processes,** which project inward around the margin of the crystalline lens.

The **ciliary muscle** is important in accommodation. It is in the shape of a muscular ring surrounding the margin of the choroid just outside the ciliary processes. In front it is attached

FIG. 85.

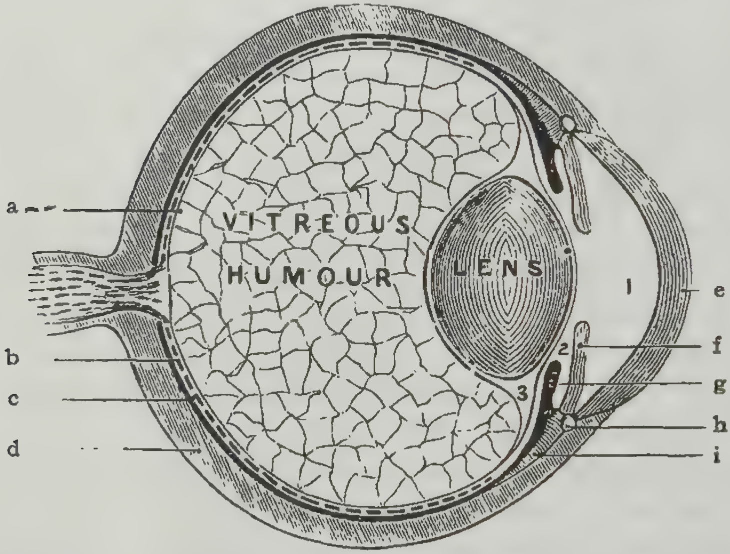


Diagram of a vertical section of the eye. (From *Yeo* after *Holden.*)

1, anterior chamber filled with aqueous humor; 2, posterior chamber; 3, canal of Petit; a, hyaloid membrane; b, retina (dotted line); c, choroid coat (black line); d, sclerotic coat; e, cornea; f, iris; g, ciliary processes; h, canal of Schlemm or Fontana; i, ciliary muscle.

to the line of junction of the cornea and sclerotic and to the ligament on the anterior surface of the iris; behind it is lost in the substance of the choroid. Its contraction, therefore, compresses the vitreous humor and relaxes the suspensory ligament of the lens. The **iris** is a circular veil hanging in front of the lens. It presents a perforation a little to the nasal side of its center, the **pupil.** It is attached in the corneo-sclerotic line. It contains circular and radiating fibers. The iris divides the space between

the cornea and lens into two chambers, **anterior** and **posterior**—the latter of which is very small. The "color of the eyes" depends on the color of the anterior surface of the iris; its posterior surface has a constant dark purple hue. The size of the pupil is subject to variations to be noted later.

Inside the choroid is the **retina**, which is that part of the eye *capable of receiving impressions of sight.* Anteriorly it reaches nearly to the ciliary processes. Externally it is in contact with the choroid, and internally with the hyaloid membrane of the vitreous humor. It is penetrated by the optic nerve a little within and below the center of the posterior hemisphere. Just external to the point of entrance of the nerve is the **macula lutea,** a small yellow area in the center of which is the **fovea centralis;** this last is exactly in the axis of distinct vision. Nine layers of cells are usually described as composing the retina. From without inward they are (1) the *pigment layer*, (2) *rods and cones*, (3–6) the four *granular layers*, (7) *nerve cells*, (8) *expansion of fibers of the optic nerve*, (9) the *limitary membrane.* Of these, the most important is the layer of **rods and cones.** The rods, or cylinders, extend through the thickness of the membrane and have between them, at intervals, flask-shaped bodies, the cones. At the macula lutea only the cones exist. Elsewhere the rods are more abundant than the cones. The length of the cones is about half that of the rods, and they occupy the inner aspect of the membrane. The layer of nerve cells presents cells communicating on the one hand with the rods and cones and on the other with fibers of the optic nerve. The rods and cones are the only parts of the retina *possessing special sensibility*, impressions being conveyed from them to the brain by the optic nerve. The fibers of the second nerve, composing one layer, are pale and transparent. The blood supply of the retina is from the **arteria centralis retinæ,** which enters the optic nerve just before it expands, and, running in its substance, is distributed as far as the ciliary processes anteriorly.

The **Crystalline Lens** is a biconvex transparent body situated just behind the iris. Its function is to *refract* the rays of light, and its action in this respect is similar to such lenses in optical instruments. It is held in place by the suspensory ligament. Its anterior convexity is more marked than its posterior. It is enveloped by a thin transparent capsule.

The **Suspensory Ligament** is a continuation of the anterior layer of the hyaloid membrane of the vitreous humor. When this layer reaches the edge of the lens (coming forward) it divides into two parts, one passing in front of and the other behind that body; the divisions are continuous respectively with the anterior and posterior portions of the capsule of the lens. The ligament supports the lens.

The **Aqueous Humor** is behind the cornea and in front of the lens and suspensory ligament. The iris has been said to separate this cavity into anterior and posterior chambers communicating through the pupillary opening. The aqueous humor is colorless and perfectly transparent. It serves to refract the rays of light, having for that purpose the same index as the cornea.

The **Vitreous Humor** occupies about the posterior two-thirds of the globe, and is back of the lens and suspensory ligament surrounded by the delicate hyaloid membrane. It is of a gelatinous consistence, and is divided into numerous compartments by very delicate membranes radiating from the point of entrance of the optic nerve. It is a transparent refracting medium.

Ocular Refraction.—In order for the image of an object to be *distinct* the rays passing from it must fall on a single portion of the retina, viz., the **fovea centralis.** The sensibility of the retina to light decreases in passing away from the fovea. All rays would not meet on the retina unless they were refracted; and for this purpose there are the cornea, the aqueous humor, the lens and the vitreous humor. The surfaces of the cornea and lens are the most important of these. Since the two surfaces

of the cornea are parallel, the external surface alone is concerned in refraction. The center of distinct vision (fovea) is in the axis of the lens precisely in the plane upon which the rays of light are brought to a focus by the refracting media. Refraction by the cornea alone would focus the rays *behind* the retina; hence the necessity of convex lenses before the eye after operations for cataract. Rays leaving the cornea are refracted by the anterior surface of the lens, by its substance to a certain extent, and again by its posterior surface, the normal mechanism being such that all rays are focused on the fovea. The rays cross each other after refraction, and the image is inverted, but the brain takes no notice of this fact, and objects are seen in their natural positions.

Accommodation.—Accommodation means a change in the convexity of the lens, whereby images are focused on the retina, whether the object be far away from or near the eye. Rays of light from distant objects strike the eye practically parallel, and we may assume that there is a certain "passive" condition of the refracting media which will bring such rays to a focus at the proper point. But when the object observed is near the eye a change in the arrangement of the media, or of the convexity of their surfaces, is necessary to prevent the focusing of the rays behind the retina. The desired end is accomplished by increasing the convexity of the lens. When the ciliary muscle is "passive" the capsule compresses the lens, decreasing its convexity to a minimum; from the attachments of this muscle, already noted, its contraction is attended by a relaxation of the suspensory ligament, which in turn relieves in some degree the compression of the capsule upon the lens and allows its antero-posterior diameter to increase; the result is increased convexity of the lens.

When distant objects are looked at the lens become flatter as a result of contraction of the suspensory ligament, which contraction is a consequence of the relaxation of the ciliary muscle. Accommodation for distant objects seems a passive process entirely.

The ciliary muscle is the "muscle of accommodation."

The contraction of the pupil for near objects is not, properly speaking, a part of accommodation.

Then, granting special sensibility to the retina and optic nerve, the formation and appreciation of an image is simple. Rays of light having passed through the cornea and aqueous humor are admitted by the pupil to pass through the lens and vitreous humor. By all these objects they are refracted so that they cross each other and fall upon the retina, producing an inverted image there. The size of the pupil, other things being equal, is regulated by the intensity of the light, the opening being contracted to admit less when the light is strong.

Myopia, Hyperopia and Presbyopia.—Sometimes the antero-posterior diameter of the eye-ball is too long and the rays of light are brought to a focus in front of the retina. Such a condition is known as **myopia**; the person will be near-sighted. He brings objects near his eyes so that the rays may have a greater divergence and thus be focused farther back. Or the rays may be scattered by placing concave lenses before the eyes. Sometimes, too, the antero-posterior diameter may be too short and the rays come to a focus behind the retina. Such a condition is known as **hyperopia**; the person will be far-sighted. He holds objects far away from his eyes that the rays from them may strike the ball with less divergence and thus be focused farther forward. Or the same end may be accomplished by placing convex lenses before the eyes. In old age the lens becomes flattened and accommodates itself less easily. This tends to focus light behind the retina and objects have to be held far away from the eye. This is known as **presbyopia**. Its remedy is the same as that for hyperopia.

Reaction to Light.—Regarding the reaction of the pupil to light, it is evident that this is mainly a reflex nervous phenomenon, though direct light will cause the muscular tissue of the iris to contract. The direct influence of the third nerve on the

action of the iris has been referred to under a consideration of that nerve. Reflexly, the pupil is contracted by light by the conveyance of an impression to the brain through the optic fibers, a message is sent to the proper center, and a stimulus is reflected through the third nerve to the sphincter of the iris causing it to contract. When the optic nerve is cut the circuit is broken, and movements of the iris do not occur from the admission of light. Practically, then, when much or little light reaches the retina the pupil contracts or dilates, as the case may be, in an effort to keep the amount constant.

Binocular Vision.—It is evident that when a person looks at an object two images are formed—one on each retina—but they are combined in his consciousness and he sees but one object. If one of the balls be thrown out of the proper axis, by pressure, *e. g.*, objects appear double. The same is true in strabismus, at least until the person has grown accustomed to the defect. In normal vision the rays from an object are formed on the fovea centralis of each eye—that is, upon corresponding points which are, for each, the centers of distinct vision.

4. The Sense of Taste.

In order that gustatory sensation may be exercised it is necessary (1) that there be specially endowed nerves and nerve centers; (2) that the nerve terminals be excited by sapid (tastable) materials; (3) that these substances be in solution. It has already been seen that the special nerves of taste are (*a*) the *chorda tympani* distributed to the anterior two-thirds of the tongue, and (*b*) the *glosso-pharyngeal* to the posterior third of that organ. It is probable that only the dorsum of the tongue, the lateral parts of the soft palate, the uvula and the upper pharynx are concerned in gustation. On the tongue are found special papillæ, (1) the **circumvallate,** large and few in number, near the base of the organ, and (2) the **fungiform,** about 200 in number, over the remaining area. The circumvallate and some of the fungiform

papillæ contain **taste beakers,** true gustatory organs. They are ovoid collections of cells beneath the epithelial covering of the mucous membrane. Sapid substances enter these beakers in solution and come in contact with the taste cells, which are connected with the filaments of the gustatory nerves. Thus are produced specific impressions which are conveyed to the gustatory center, and the sense of taste is excited. The limited distribution of the taste beakers makes it impossible that they should be the only organs capable of receiving special gustatory impressions. The **taste center** has been indefinitely located in the uncinate gyrus near the olfactory center.

Since it is necessary to the tasting of substances that they come in actual contact with the taste organs, and since to do so they must be in solution, it follows that dryness of the mouth interferes with, or abolishes, this sense.

The most marked tastes are the sweet, bitter, saline, and alkaline. The more delicate flavors involve also the special sense of smell, and it has been seen that dissociation of the two kinds of impressions is often impossible. Taste is also subject to variations by reason of education, age, association, caprice, etc. Bitters are most easily appreciated at the back, salts and sweets at the tip, and acids at the sides of the tongue.

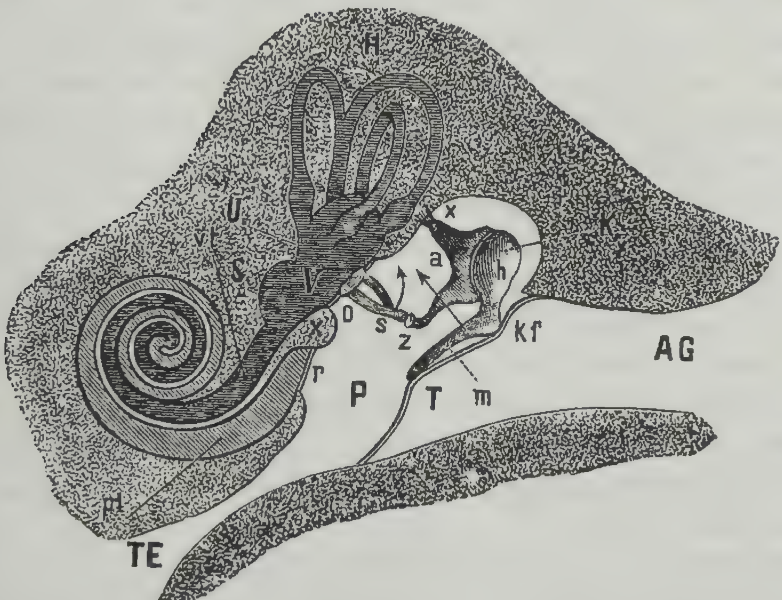
5. The Sense of Hearing.

The ear consists of a complicated apparatus for the purpose of the reception of special impressions which are appreciated by the brain as sounds. Anatomically it consists of the **external,** the **middle** and the **internal** ear; the last contains the essentials of the auditory apparatus, the external and middle divisions serving only to concentrate the sound waves upon the parts of the internal.

The External Ear.—This consists of the **pinna** and the **external auditory canal.** The pinna is the external visible portion, and consists of the large cavity, the **concha,** into which the

external auditory canal opens externally; of two prominent ridges partly surrounding the concha, the **helix** outside and the **antehelix** internal to this; and of a fibro-cartilaginous process projecting backward in front of the concha, the **tragus.** The

FIG. 86.



Scheme of the organ of hearing.

AG, external auditory meatus; T, tympanic membrane; K, malleus with its head (h), short process (kf) and handle (m); a, incus, its short process (x) and its long process united to the stapes (s) by means of the Sylvian ossicle (Z); P, middle ear o, fenestra ovalis; r, fenestra rotunda; x, beginning of the lamina spiralis of the cochlea; pt, scala tympani, and vt, scala vestibuli; V, vestibule; S, saccule; U. utricle; H, semicircular canals; TE, Eustachian tube. The long arrow indicates the line of traction of the tensor tympani; the short curved one, that of the stapedius (*Landois.*)

external auditory canal runs inward and slightly forward from the concha to terminate at the membrana tympani, or drum. Its inner part is in the petrous portion of the temporal bone; its external part is fibro-cartilaginous in structure. The whole is lined by integument.

The Middle Ear (Tympanum).—This is a cavity at the bottom of the external auditory canal in the petrous portion of

the temporal bone, containing ossicles for the conduction of sound waves to the internal ear. The cavity communicates, through the Eustachian tube, with the pharynx, and this is its only direct connection with the external air, though it does communicate with the mastoid air cells. It is lined by mucous membrane. The **membrana tympani,** separating it from the external auditory canal, is fibrous in structure. It is lined externally by skin and internally by mucous membrane.

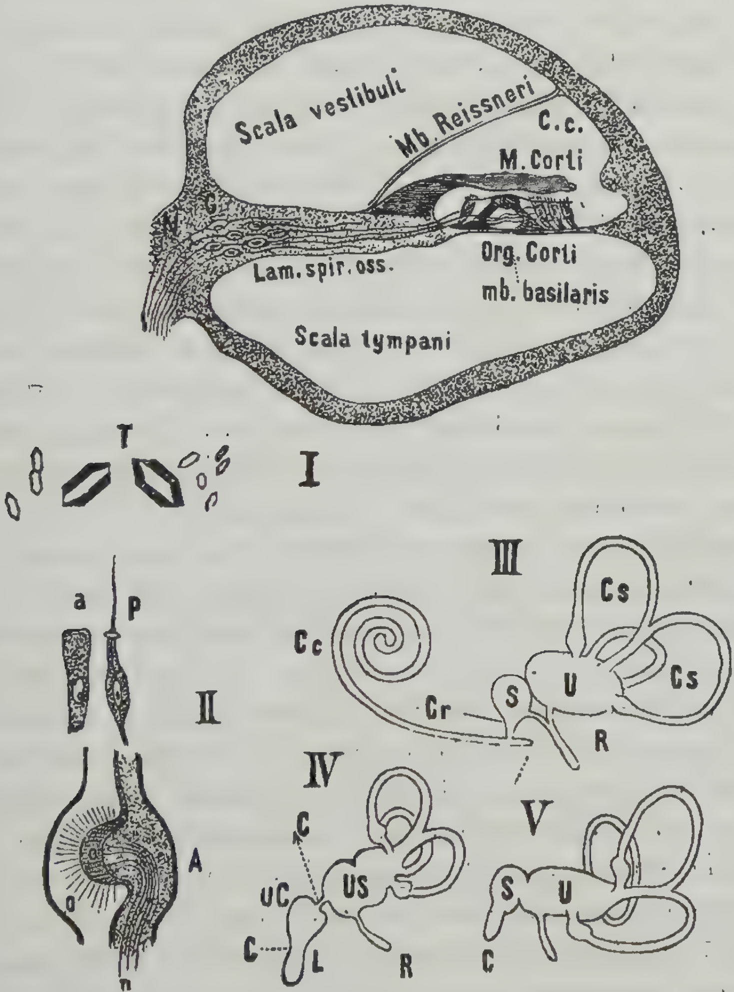
The three ossicles of the middle ear are the **malleus, incus** and **stapes.** The **malleus,** shaped like a hammer, is attached in a vertical direction to the upper radius of the membrana tympani, and articulates by its head with the incus. The **incus** has the shape of an anvil; its base articulates with the malleus, while its small extremity curves downward to articulate with the neck of the stapes. The base of the **stapes** is applied to the membrane covering the fenestra ovalis. The **tensor** and **laxator tympani** are attached to the neck of the malleus; the **stapedius** to the neck of the stapes. These bones constitute a chain, which conveys the vibrations of the membrana tympani to the fenestra ovalis.

The Internal Ear (Labyrinth).—This consists of a series of cavities in the petrous portion of the temporal bone lined by a peculiar membrane. When the bony substance surrounding these cavities is carefully removed it is found that that portion immediately outside them is harder than the adjacent structure. This constitutes the **bony labyrinth,** while the membrane inside the bony walls is the **membranous labyrinth.**

The **bony labyrinth** consists of the vestibule, cochlea and semicircular canals. The **vestibule** occupies the mid-portion of the labyrinth, and is that part with which the middle ear communicates by the fenestra ovalis; it communicates also with the cochlea and semicircular canals, and on its internal aspect are openings for the entrance of some of the branches of the auditory nerve. The **cochlea,** shaped like a snail shell, runs off

from the front of the vestibule, winds about two and a half times around a cone-shaped central axis—the modiolus—and ends

FIG. 87.



I, Transverse section of a turn of the cochlea; II, A, ampulla of a semicircular canal with the crista acustica; a; auditory cells, p, provided with a fine hair; T, otoliths; III, scheme of the human labyrinth; IV, scheme of a bird's labyrinth; V, scheme of a fish's labyrinth. (*Landois.*)

in a blind apex. The canal of the cochlea is partially separated into two compartments by a bony plate, the **lamina spiralis.**

The **basilar membrane** completes the septum and divides the lumen of the cochlea into two canals, the **scala tympani** and the **scala vestibuli**, corresponding in name to the tympanic and vestibular openings of the cochlea. The **semicircular canals**, three in number—superior, external and posterior—describe arches from the posterior aspect of the vestibule, communicating by both their extremities with that cavity.

The **membranous labyrinth** consists of a special membrane lying inside the bony labyrinth and corresponding in general outline to the walls of the cavity. It is, however, separated from the walls by **perilymph**, and encloses a similar fluid, the **endolymph**. It covers the sides of the lamina spiralis in the cochlea and completes the septum, besides following the wall proper; and on one side it sends a distinct process from the tip of the lamina spiralis to the wall of the canal, so that there are in reality three divisions of the lumen of the cochlea. This process is the **membrane of Reissner**, and the third canal is the **scala media** the true membranous cochlea. (See Fig. 87.)

Termination of Auditory Nerve.—The membranous labyrinth, containing and being suspended in fluid, receives the terminal filaments of the eighth nerve as well as all the sonorous vibrations intended for that nerve. When the auditory nerve has reached the base of the internal auditory meatus it enters the internal ear by two divisions, one for the vestibule and semicircular canals and the other for the cochlea. The **vestibular** portion again subdivides, sending one branch to the utricle and superior and horizontal semicircular canals, and another to the saccule and posterior semicircular canal. The fibers of the eighth nerve spread out over the inner surface of the membrane to end in a way somewhat obscure. The membrane is lined internally by epithelium whose character differs in different areas. In the region of distribution of the vestibular portion of the nerve the cells are of two kinds, **hair cells** and **rod cells**. From the inner ends of the hair cells ciliated processes project into the en-

dolymph; to their outer ends pass the axis cylinders of the nerve fibers, though the exact mode of connection is not clear. The rod cells are much more numerous than the hair cells, but their precise connection with audition is not apparent.

Upon the basilar membrane are the **rods of Corti.** They consist of two sets of pillars of varying length, slanting towards each other, thus leaving at their base a space which becomes a canal by a longitudinal succession of these pillars. There are supposed to be about 4,500 elements in the outer and 6,500 in the inner set of these rods. Intimately associated with the pillars are large numbers of hair cells with which the auditory nerve filaments may communicate; it is certain that these filaments are closely connected in some way with the pillars.

Functions of the Semicircular Canals.—The use of these is obscure. Their destruction is not followed by interference with hearing, although auditory filaments are distributed to some parts of them. Curiously enough, however, this lesion is one of the three chief ones interfering so markedly with equilibration—the phenomena following it being not unlike those sequent upon lesions of the cerebellum and the posterior white columns of the cord.

Functions of the Cochlea.—While the exact mechanism of the production of auditory impressions is unknown, there seems to be no doubt that such mechanism takes place almost entirely in the cochlea, and that fibers which convey to the auditory centers impressions of sound are distributed to the *organ of Corti* therein. That is to say, loss of the sense of hearing supervenes upon destruction of this part of the internal ear. In physics it is known that for a sound, for example of a piano string, to be heard the membrana tympani must vibrate in unison with the sonorous vibrations of the cord; that is, "consonating bodies" repeat sonorous vibrations, giving them their proper pitch and quality. It has been supposed that the thousands of rods of Corti, of varying length and size, in the cochlea are made to

vibrate separately or in correctly associated collections (like the strings of a harp), and thus reproduce communicated vibrations, and so give rise to impressions which, conveyed by the auditory nerve to the center, are there recognized as sounds of different degrees of intensity, pitch and quality. This theory may be true, but its correctness is probably beyond the range of experimental proof.

While the usual mode of conduction of sound waves to the cochlea is through the external ear, they may reach it in other ways, as through the bones of the head, or through the Eustachian tube. Nor is the integrity of the membrana tympani actually necessary to the production of sound; although practically speaking a person in whom this organ is destroyed is deaf, he can hear if the ossicles can in some way be placed in vibration by sound waves, as by the intervention of an artificial membrane. Indeed is has already been seen that none of the parts of the external or middle ear are actually necessary to hearing. They are only accessory conveniences for the better transmission of impressions to the filaments of the auditory nerve.

The (so-called) **tensor** and **laxator tympani** muscles make tense or lax the membrana tympani, thus influencing the rapidity and amplitude of its vibrations, and therefore the pitch and intensity of the sound. The **stapedius** prevents too great movement of the stapes. The free communication of the air in the tympanum with that in the mastoid cells and pharynx insures an approximately constant internal pressure upon the membrane, and thus precludes accidents which would otherwise interfere with its proper vibration.

The **auditory center** in man is in the first and second temporal convolution of the temporo-sphenoidal lobe.

Briefly then, the physiology of hearing is as follows: Sound waves collected by the pinna enter the external auditory canal and impinge upon the membrana tympani. The drum is thus set to vibrating and communicates its movements to the ossicles,

which in turn hand them over through the fenestra ovalis to the fluids of the internal ear, through which media they reach the auditory filaments, are conducted to the brain and given proper recognition.

The Production of the Voice.

The production of the voice is not connected with the special senses, but its consideration will be introduced here for the sake of convenience.

The **Larynx** is the organ of voice. It is a cavity closed except for its openings above and below. It consists of four cartilages—*cricoid*, *thyroid* and *two arytenoid*—joined together by ligaments and muscles. The vocal cords are attached posteriorly to the bases of the movable arytenoid cartilages and anteriorly to the angle between the alæ of the thyroid. The muscles serve to move the cartilages and thus to separate or approximate and to render lax or tense the vocal cords.

Production of Sound.—The human voice is produced by vibrations of the vocal cords, which vibrations are set up by currents of expired air.

Movements of the Vocal Cords.—These are those taking place (1) in respiration and (2) during vocalization.

1. *In Respiration*.—When the cords are "passive" they are approximated anteriorly and separated posteriorly, so that the interval between them (rima glottidis) is triangular. This interval becomes a little wider during inspiration and a little narrower during expiration.

2. *In Vocalization.*—The production of sound in the larynx involves an *approximation* of the cords and an increase in their *tension.* They are made more nearly parallel by the approach of the arytenoids to each other, and the rima glottidis assumes the shape of a mere chink. The tenser the cords, the higher the note produced; usually also the closer the cords are brought together, the higher the note. The range of the voice depends

principally on the degree of *tension* which the cord can be made to assume.

Varieties of Vocal Sounds.—These are mainly (1) monotonous, (2) transitional, (3) musical.

1. In monotonous sounds the notes have all nearly the same pitch, as in reading.

2. In transitional sounds there is a gradual change in the tension and approximation of the cords, so that the notes become successively higher or lower, as in the howling of a dog.

3. In musical sounds the vocal cords have a definite number of vibrations for each successive note—a number corresponding to the production of that note in the musical scale.

The range of the average human voice is from one to three octaves. The highest and lowest notes of females are about one octave higher than the corresponding notes of males. The chief difference between male and female voices is, therefore, one of *pitch;* but they also differ materially in *tone*. The difference in pitch is a result of the different *length*, and therefore the different rate of vibration, of the cords in the two sexes. The female cords are about two-thirds the length of the male.

Before puberty the male larynx resembles the female, but at that period the alæ of the thyroid becomes more prominent in the male and the cords increase in length, thus accounting for the change of voice.

In old age control of the musculature of the larynx is partly lost, the cords become altered and the cartilages ossify. These circumstances make the voice weak and unsteady.

Speech.—Modifications and alterations of the sounds produced in the larynx during and after their production result, under the influence of the sensorium, in articulate *speech*. These modifications are made chiefly by the tongue, teeth and lips.

The speech sounds are divided into *vowels* and *consonants*. The distinction is that the vowel sounds are generated in the larynx, while the consonant sounds are produced by alterations

in the current of air above the larynx, and cannot be pronounced except *consonantly* with a vowel. The current is modified mainly by the tongue and teeth in the formation of linguals and dentals, by the cavity of the nose in case of nasals, and by changes in the shape and size of the oral cavity in the production of other sounds.

Nervous Supply of the Larynx.—The superior laryngeal branch of the teeth is the sensory nerve, which guards the glottis to prevent the entrance of foreign bodies. Impressions made on the filaments of this nerve are reflected through the medulla and inferior laryngeal branch of the tenth to the muscles which close the glottis. The inferior laryngeal also innervates the muscles that vary the tension of the cords, and the superior laryngeal keeps the mind informed of the state of these muscles and of the necessity for forced expiration or coughing.

CHAPTER XII.

REPRODUCTION.

VERY many facts in our knowledge of reproduction depend on observations made upon lower animals, but there is sufficient analogy between the known facts connected with human reproduction and development and those of the same stages in other groups of beings to enable us to present, as at least approximately accurate, certain broad principles regarding the process as it pertains to the human race.

In order that a human being may be brought into existence it is necessary that there be a union of the male element, the spermatozoön, and the female element, the ovum. Both these sexual cells are developed from epithelium—the spermatozoön from that of the seminiferous tubules of the male, and the ovum from the germinal layer of the ovary.

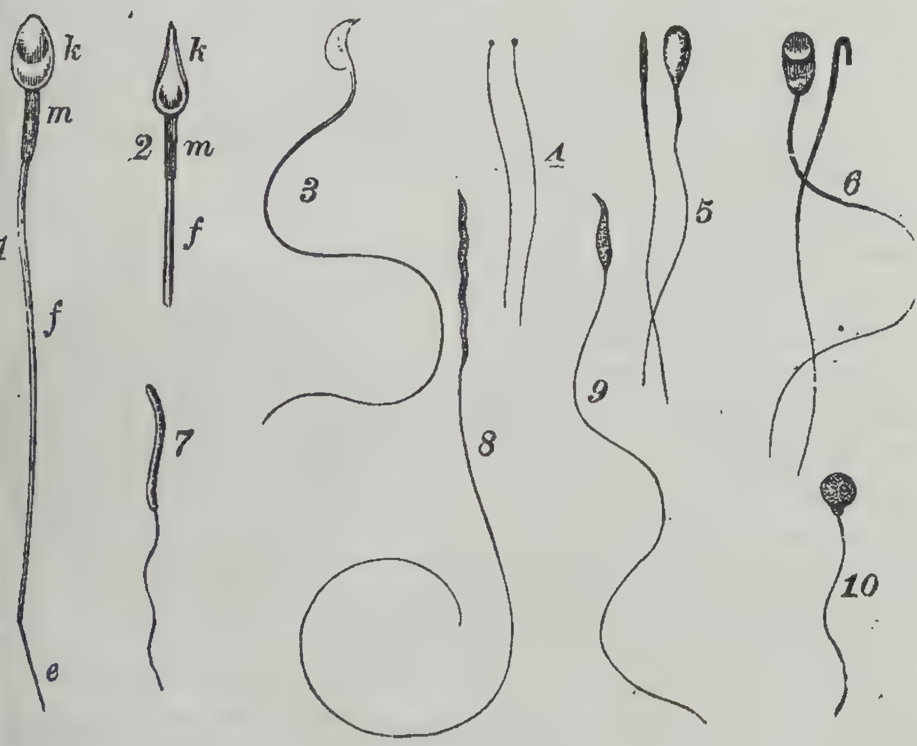
In what follows reference will be had to reproductive processes in the human being.

Spermatozoa.—Human spermatozoa (Fig. 88) are elongated bodies, about one five-hundredth of an inch in length, and consist of three parts, head, mid-portion and tail. The last-named part is about four-fifths the length of the entire spermatozoön. The head is egg-shaped and much the thickest part of the element. A slender filament, the *axial fiber*, extends throughout its length from head to tail and projects slightly beyond the latter. Spermatozoa are possessed of wonderful vitality. They live for several weeks in the genital passages of the female. In the male genital passages they may live for months in a quiescent state. The nucleus is the fertilizing agent. Spermatozoa are also

remarkable for their power of locomotion, which is effected by lashings and rotary movements of the tail.

Ova.—The ovum (Fig. 89), or female sexual cell, is the largest cell to be found in the human body. Its diameter is about $\frac{1}{125}$ of

FIG. 88.



Spermatozoa.

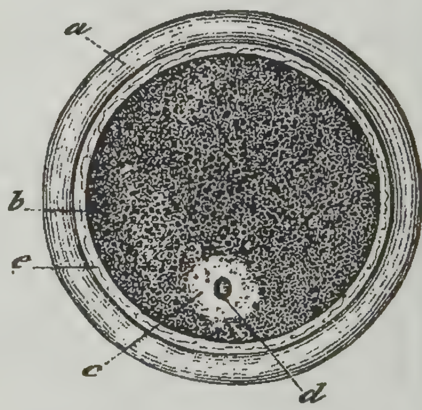
1, human (× 600), the head seen from the side; 2, on edge; *k*, head; *m*, middle piece; *f*, tail; *e*, terminal filament; 3, from the mouse; 4, bothriocephalus latus; 5, deer; 6, mole; 7, green woodpecker; 8, black swan; 9, from a cross between a goldfinch (m.) and a canary (f.); 10, from cobitis. (*Landois.*)

an inch. Its structure is that of a typical cell. When the ovary is developing a part of its covering epithelium dips down into the substance of the organ and becomes walled off by union of the surface cells above it. A part of this ball of epithelium becomes the ovum, and a part the Graafian follicle for that ovum. The

youngest ova are thus found nearest the surface of the ovary. The cell has an enveloping membrane, the *vitelline membrane*, a protoplasm, the *vitellus*, a nucleus, the *germinal vesicle*, and a nucleolus, the *germinal spot*. Outside the ovum, but not strictly a part of it, is the *zona pellucida*, a transparent envelope, and outside the zona pellucida a collection of cells, the *corona radiata*. The *perivitelline space* is between the ovum proper and the zona pellucida. The zona presents radial striæ, which may facilitate the entrance of the spermatozoön.

Ova are capable of being impregnated as long as 7–9 days after their discharge from the ovary. Their formation begins early in fetal life. The ovum possesses no power of independent motion. It is passive in fecundation; it is sought by the male element. Its vitellus, or yolk (protoplasm), contains nutritive non-living material, deutoplasm, whose function is to furnish food substance to the impregnated ovum until the fetal circulation is established. Deutoplasm in the human ovum is scarcely to be distinguished from the living protoplasm, though in the ova of birds, *e. g.*, it is clearly marked off, and constitutes the main bulk of the mature egg, since the developing embryo receives no blood from the mother.

FIG. 89.



Ovum. (From *Yeo* after *Robin*.)

a, zona pellucida and vitelline membrane; *b*, yolk; *c*, germinal vesicle or nucleus; *d*, germinal spot or nucleolus; *e*, interval left by the retraction of the vitellus from the zona pellucida.

Graafian Follicles.—The Graafian follicles are directly concerned in the development and maturation of ova. These are small vesicles in the cortical ovarian substance surrounded by a capsule of thickened ovarian stroma, the *tunica vasculosa*. Inside the tunica vasculosa, lining the spherical cavity of the ves-

icle, are several layers of epithelial cells making up the *membrana granulosa.* The cavity is filled with an albuminous liquid, the

FIG. 90.

Section of the ovary of a cat, showing the origin and development of Graafian follicles. (From *Yeo* after *Cadiat.*)

a, germ epithelium; *b*, Graafian follicle partly developed; *c*, earliest form of Graafian follicle; *d*, well-developed Graafian follicle; *e*, ovum; *f*, vitelline membrane; *g*, veins; *h*, *i*, small vessels cut across.

liquor folliculi. At one point in its circumference the membrana granulosa is much thickened, and in this thickened portion is imbedded the ovum. The epithelial cells of the membrana

completely surround the ovum, constituting the *discus proligerus*. The cells of the discus next the ovum have their long axes at right angles to the circumference of the egg, and this layer is the corona radiata already mentioned. The zona pellucida is just underneath the corona.

Usually a Graafian follicle contains only one ovum. The follicles and their contained ova begin to be formed early in fetal life. Probably none are newly formed after the child is two years old, but they are undeveloped before puberty. It is estimated that some 72,000 follicles and ova exist in the two ovaries of the average woman; but of these not more than 400 reach full development, the others undergoing retrograde changes and disappearing.

Up to puberty the follicles and ova are small, but at that time some of them begin to enlarge, and at more or less regular intervals one of these follicles bursts and allows the escape of its contained ovum into the fimbriated extremity of the Fallopian tube —a process known as *ovulation*. Previous to its rupture the Graafian follicle has been enlarging. It is always located in the cortical part of the ovary, but it may now not only form a distinct protrusion above the surface of the organ, but may by its size encroach upon the medullary portion. It may at this time have a diameter of half an inch. Meantime the more superficial part of the tunica vasculosa has been undergoing fatty degeneration, has lost its blood supply and become very thin. Here rupture occurs, and the mature ovum, ready for impregnation, escapes upon the surface of the ovary.

Corpus Luteum.—When the ovum has been extruded hemorrhage occurs, filling the empty follicle with blood. By contraction of the extra-vesicular adjacent tissue the walls of the Graafian follicle become folded into the cavity. Soon proliferation of the cells of the follicular wall takes place into the blood clot, vascular loops are formed, and the tunica vasculosa itself becomes greatly hypertrophied. The clot later disappears and

the mass then has a yellowish color and is known as the *corpus luteum.*

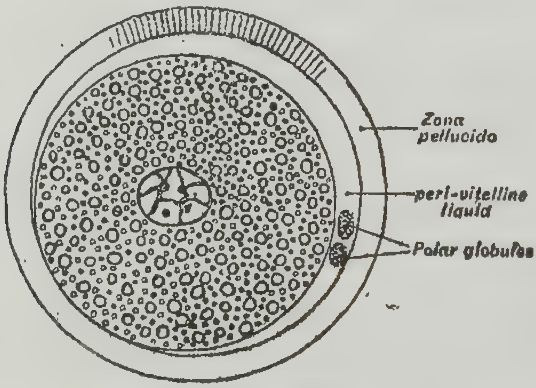
Whether or not the ovum that escaped from the follicle which was the antecedent of any given corpus luteum was impregnated, has an influence upon the growth of that corpus. If the ovum failed of fecundation the corpus luteum will reach its highest development in about fifteen days, and will then assume the character of cicatricial tissue and be absorbed in a few weeks. If the ovum was fecundated, the corpus luteum will increase in size for some three months, until it may be half the size of the ovary. At labor it has been reduced to a white cicatrix, which probably persists as a small nodule throughout life. The differences between the corpora lutea of menstruation and pregnancy are shown by the following table from Dalton:

	Corpus Luteum of Menstruation.	Corpus Luteum of Pregnancy.
At the end of three weeks.	Three-quarters of an inch in diameter; central clot reddish; convoluted wall pale.	
One month.	Smaller; convoluted wall bright yellow; clot still reddish.	Larger; convoluted wall bright yellow; clot still reddish.
Two months.	Reduced to the condition of an insignificant cicatrix.	Seven-eighths of an inch in diameter; convoluted; wall bright yellow; clot perfectly decolorized.
Four months.	Absent or unnoticeable.	Seven-eighths of an inch in diameter; clot pale and fibrinous; convoluted wall dull yellow.
Six months.	Absent.	Still as large as at the end of second month; clot fibrinous; convoluted wall paler.
Nine months.	Absent.	Half an inch in diameter; central clot converted into a radiating cicatrix; external wall tolerably thick and convoluted, but without any bright yellow color.

Maturation.—But previous to its discharge from the Graafian follicle, the ovum undergoes certain changes—a ripening process

—whereby it is made ready to receive and be impregnated by the spermatozoön. This maturation consists in the discharge from the cell proper of a part of its nucleus and a part of its protoplasm. The nucleus moves toward the periphery, and the perinuclear membrane is lost. As the nucleus approaches the surface of the egg it undergoes karyokinesis, and a part of it, together with a little surrounding protoplasm, is extruded and

FIG. 91.



The fertilized ovum, or blastosphere. (*Kirkes.*)

finds itself in the perivitelline space. This is the *first polar body*. A *second polar body* is likewise later discharged by karyokinetic division. (See Fig. 91.)

The object of this extrusion and the final fate of the polar bodies are matters of speculation. That portion of the nucleus which remains after the polar bodies have been thrown off finds its way back to the center of the ovum. It soon develops a covering membrane, and is now the *female pronucleus*, ready for union with the male pronucleus. It is about the time of the completion of this process that the follicle ruptures and the discharge of the ovum—ovulation—occurs.

Ovulation.—It is supposed that from puberty to the menopause one (or more?) ovum is discharged at tolerably regular intervals of about four weeks. It should, and usually does, enter

the outer end of the Fallopian tube, to be conveyed toward the uterus. Obviously only a few, and sometimes none, are ever impregnated. Should the ovum fail to reach the uterus and become fecundated, ectopic gestation will be the result.

The patent fimbriated extremity of the tube may grasp the ovary at the time of rupture of the Graafian follicle, but this is not probable. One of the tubal fimbriæ is attached to the outer extremity of the ovary and has on its surface a small linear depression lined by ciliated epithelium and leading to the tube. The ovum very likely in most cases drops into this depression, and the influence of the cilia is to carry it towards the tube.

Menstruation.—Usually between the fourteenth and seventeenth years of female life menstruation begins. It is a discharge of blood, epithelium and other parts of the mucous membrane of the uterine cavity, together with mucus from the glands of the uterus and vagina. About the beginning of menstrual life there are marked changes in bodily development, Graafian follicles enlarge and begin to approach the surface, ovulation is begun, and the female is capable of being impregnated.

In most cases menstruation occurs at regular intervals of twenty-eight days. The function is suspended during pregnancy and usually during lactation. When it is first established it is frequently irregular in its occurrence for several months; a like irregularity usually accompanies the cessation of the function between the fortieth and fiftieth years—when the *menopause*, or *climacteric*, is established. The normal female may be impregnated during menstrual life, but not before or after.

The average length of time for which the menstrual flow continues is four days. There are many exceptions in both directions for different women, but the time for any one woman probably varies little under normal conditions. The discharge for each period averages some five ounces. It does not usually coagulate, on account of the presence of alkaline mucus. For five or six days preceding the flow, the uterine mucous mem-

brane gradually thickens, the glands become longer and more tortuous, the connective tissue cells multiply and the blood-vessels are greatly increased in size. This is apparently a preparation for the reception of the impregnated ovum. A short time before the flow begins there is hemorrhage into the subepithelial tissue, possibly by diapedesis, possibly by rupture. In a day or so the superjacent mucous membrane becomes disintegrated and is discharged with the included parts of the glands. The underlying vessels, being thus exposed, rupture and the sanguineous discharge carries away the débris.

For three or four days subsequent to the cessation of the flow the uterine mucosa is being repaired. The deeper layers, including the deeper portions of the glands, were not cast off, and the whole is reconstructed from the intact parts. Following the reconstructive period there is a stage of quiescence lasting some two weeks, until six or seven days prior to the next menstruation.

At the beginning of each menstrual flow there is general congestion of the pelvic viscera and mammary glands, accompanied usually by headache and a sense of pelvic oppression. The congestion and discomfort begin to disappear when the flow is established.

Ovulation probably in most cases takes place just before the menstrual flow begins, but neither occurrence is dependent upon the other. Ovulation has frequently been shown to take place in the inter-menstrual period, but the congestion of the reproductive organs incident to menstruation probably hastens the rupture of any Graafian follicle which at that time happens to be near the completion of its development.

The relations between ovulation, menstruation and impregnation are not definitely determined. Pregnancy lasts for ten lunar months and dates from the time of impregnation (conception), but that time cannot in any case be fixed upon with precision. The vitality of the ovum is thought not to last longer

than seven days unless impregnated, and if impregnation is to occur, it must take place within the first week after ovulation. Since, therefore, ovulation and menstruation *usually* occur together, and since impregnation probably occurs about the beginning of menstruation, we reckon from the first day of the last menstruation 280 days forward to determine the probable time of labor. This is equivalent to adding nine calendar months and seven days to the first day of the last menstrual period. It is evident that this calculation at best gives only the approximate time.

While fertilization probably occurs at the time mentioned, the spermatozoön effecting fecundation may have been in the female genital tract for weeks. Its vitality here is so prolonged that the time of its deposit with reference to menstruation very probably has little to do with whether or not conception shall occur.

Impregnation.—The term *impregnation*, or *fertilization*, or *fecundation*, is used to signify that union of the male and female sexual cells which makes possible the development of a new human being. Normally impregnation takes place in the Fallopian tube, and almost always in the outer third. The male element, the spermatozoön, seeks and penetrates the female element, the ovum. It is the blending of the nuclei (pronuclei) which is essential. Spermatozoa in large numbers swarm around the ovum and several at least enter the perivitelline space. Only one, however, is destined usually to enter the ovum. As it approaches the vitelline membrane, head first, the protoplasm of the ovum swells up into a prominence to meet it. The fertilizing spermatozoön makes its way through the vitelline membrane, losing its tail in the passage, and becomes the *male pronucleus*. The female pronucleus now advances from its central position to meet the male element, and they coalesce to become the *segmentation nucleus*. Impregnation has now taken place. The segmentation nucleus represents a new being. It contains anatom-

ical elements from both parents, and it is not surprising that the child should resemble both, anatomically and otherwise.

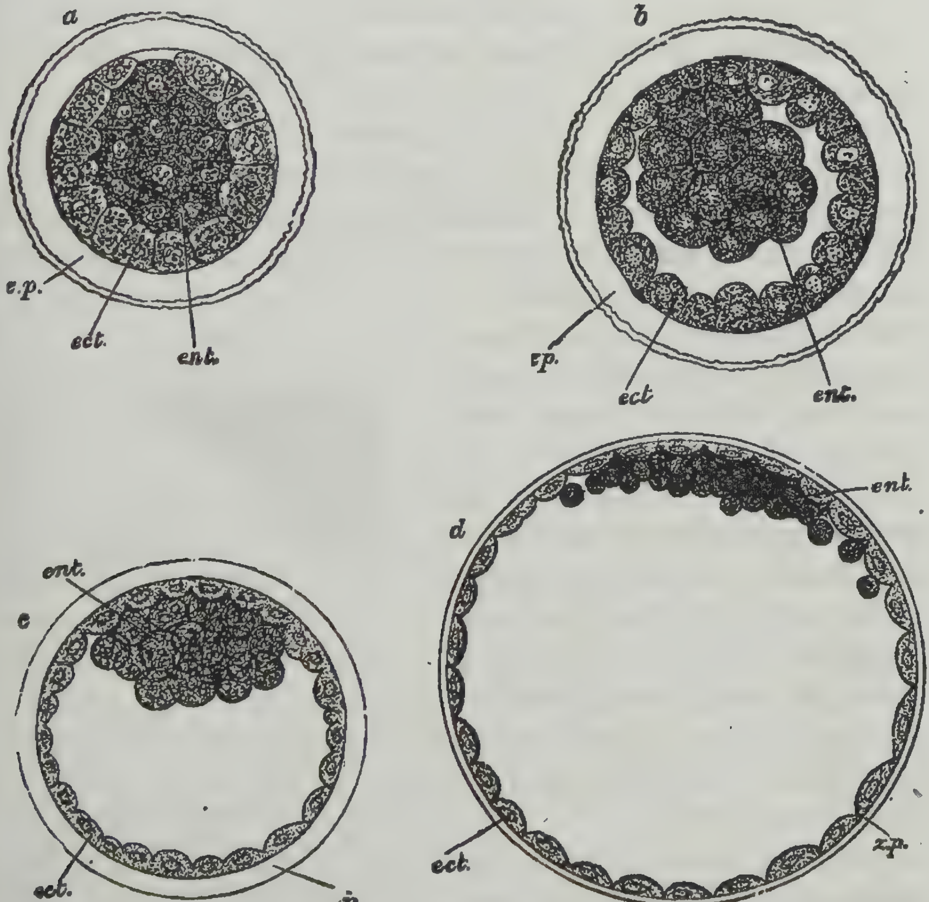
The term "ovum" has so far been used to signify the unimpregnated sexual cell discharged from the female ovary. It is also used to signify the fertilized cell, and is in fact often applied without much precision to the product of conception at almost any stage of its intrauterine development.

The fertilized ovum is carried through the tube to the uterus, arriving there some seven days after its fecundation. In its passage it becomes covered with a coating of albuminous material. This layer is probably impervious to spermatozoa—which fact may account for the practical universality of fecundation in the outer part of the tube, if at all. The coating corresponds to the white of an egg, in that it penetrates the perivitelline membrane and furnishes nutritive material to the vitellus. On reaching the uterus the ovum becomes attached to and covered by the thickened mucous membrane of that organ in a way to be noted presently. Here it remains until expelled during parturition.

Segmentation.—As soon as union of male and female pronuclei has taken place, cleavage of the ovum begins. The nucleus (segmentation nucleus) and protoplasm divide by karyokinesis to form two nearly similar cells. These two divide into four, these four into eight and so on, till a large number of cells occupy the vitelline space and are all surrounded by the perivitelline membrane. As division proceeds, cells arrange themselves around others, so that the former occupy the circumference and the latter the center of the vitelline cavity. Later, while the outer cells constitute a layer covering the entire inner surface of the perivitelline membrane, the inner cells group to form a mass which is in contact with the outer layer at one point only—like a ball lying in a relatively large hollow sphere. The space thus left between the two kinds of cells is called the *segmentation cavity.* Soon the surrounding cells become attenuated (Rauber's cells) and disappear. Their place, as a surrounding envelope,

is taken by some of the cells of the inner layer. This second surrounding layer is the *epiblast*, or *ectoderm;* the surrounded mass is the *hypoblast*, or *entoderm.*

FIG. 92.



Sections of the ovum of a rabbit, showing the formation of the blastodermic vesicle. (From *Yeo* after *E. Van Beneden.*)

a, b, c, d, are ova in successive stages of development; *Z, p,* zona pellucida; *ect,* ectomeres, or outer cells; *ent,* entomeres, or inner cells.

Before long the entoderm spreads out over a larger area, and from it and from the ectoderm is developed a layer of cells, the *mesoblast*, or *mesoderm*, which occupies a position between the

other two layers. This three-layered germ is now the *blastodermic vesicle*, or the *gastrula*, and its cavity is the *archenteron*, or *celenteron*. From these three germ layers are developed all the parts of the body by the formation of folds, ridges, constrictions, etc., and by various metamorphoses which have as their end the adaptation of structure to function.

Derivatives of the Germ Layers.—According to Heisler these are:

From the *ectoderm:* (1) The *epidermis* and its *appendages*, including the nails, the hair, the epithelium of the sebaceous and sweat glands and the epithelium of the mammary gland. (2) The *infoldings* of the *epidermis*, including the epithelium of the mouth and salivary glands, of the nasal tract and its communicating cavities, of the external auditory canal, of the anus and anterior urethra, of the conjunctiva and anterior part of the cornea, the anterior lobe of the pituitary body, the crystalline lens and the enamel of the teeth. (3) The *spinal cord* and *brain* with its outgrowths, including the optic nerve, the retina and the posterior lobe of the pituitary body. (4) The *epithelium* of the *internal ear*.

FIG. 93.

Impregnated egg.

With commencement of formation of embryo; showing the area germinativa or embryonic spot, the area pellucida, and the primitive groove and streak. (*Kirkes* after *Dalton.*)

From the *entoderm:* The *epithelium* of the respiratory tract, of the digestive tract (from the back part of the pharynx to the anus, including its associated glands, the liver and pancreas), of the middle ear and Eustachian tube, of the thymus and thyroid bodies, of the bladder and first part of the male urethra and of the entire female urethra.

From the *mesoderm:* (1) *Connective tissue* in all its forms, such as bone, dentine, cartilage, lymph, blood, fibrous and areolar tissue; (2) *muscular tissue;* (3) all *endothelial cells;* (4) the *spleen, kidney* and *ureter, testicle* and its *excretory* ducts, *uterus, Fallopian tube, ovary* and *vagina.*

The Embryonal Area.—Soon after the germ reaches the uterus (probably) there appears on its surface on oval whitish spot, the *embryonal area.* The impregnated ovum is still in the shape of a vesicle. It is from the embryonal area alone that the body is developed. The other parts are accessory. Longitudinal division of this area is supposed to give rise to twins of the same sex and of almost identical structure. Running in the long diameter of the embryonal area is a marking, the *primitive streak,* in which is a longitudinal depression, the *primitive groove.* (Fig. 93.) These surface markings are caused by thickening of the ectoderm. (Fig. 94.)

Development of Mesoderm.—It is about this time that the *mesoderm* makes its appearance. It begins under the primitive groove and extends in all directions. It originates from both ectoderm and entoderm, and lies between them. In the median line the three layers are closely united to each other. (Fig. 94.) At first the mesoderm does not completely embrace the germ, but is deficient opposite the embryonal area.

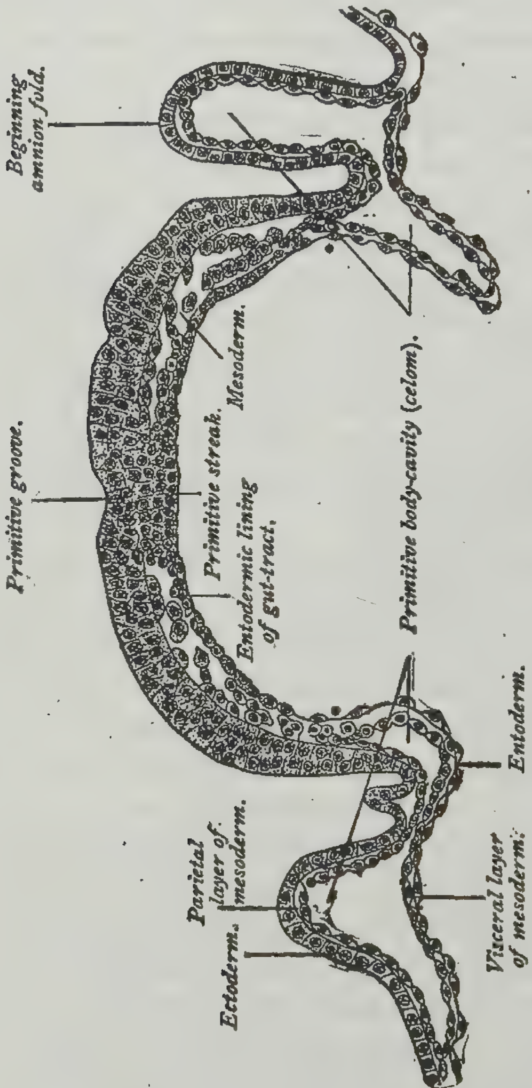
Fig. 94 shows that the cells of the mesoderm make up a thickened mass near the median line, but farther away they constitute two distinct lamellæ. The mass near the median line is the *vertebral* or *axial plate.* The outer of the lateral lamellæ is the *somatic mesoderm;* the inner is the *splanchnic mesoderm.* The ectoderm and somatic mesoderm unite to form the *somatopleure;* the entoderm and splanchnic mesoderm unite to form the *splanchnopleure.* The interval left between the somatopleure and splanchnopleure is the *celom,* or *body cavity.* (Fig. 95.) The great serous cavities of the body are developed from it.

Beginning Differentiation.—It thus appears that the embryo

is beginning to develop from the simple vesicle into specialized parts.

We shall notice briefly the development of the *body proper*, and

FIG. 94.



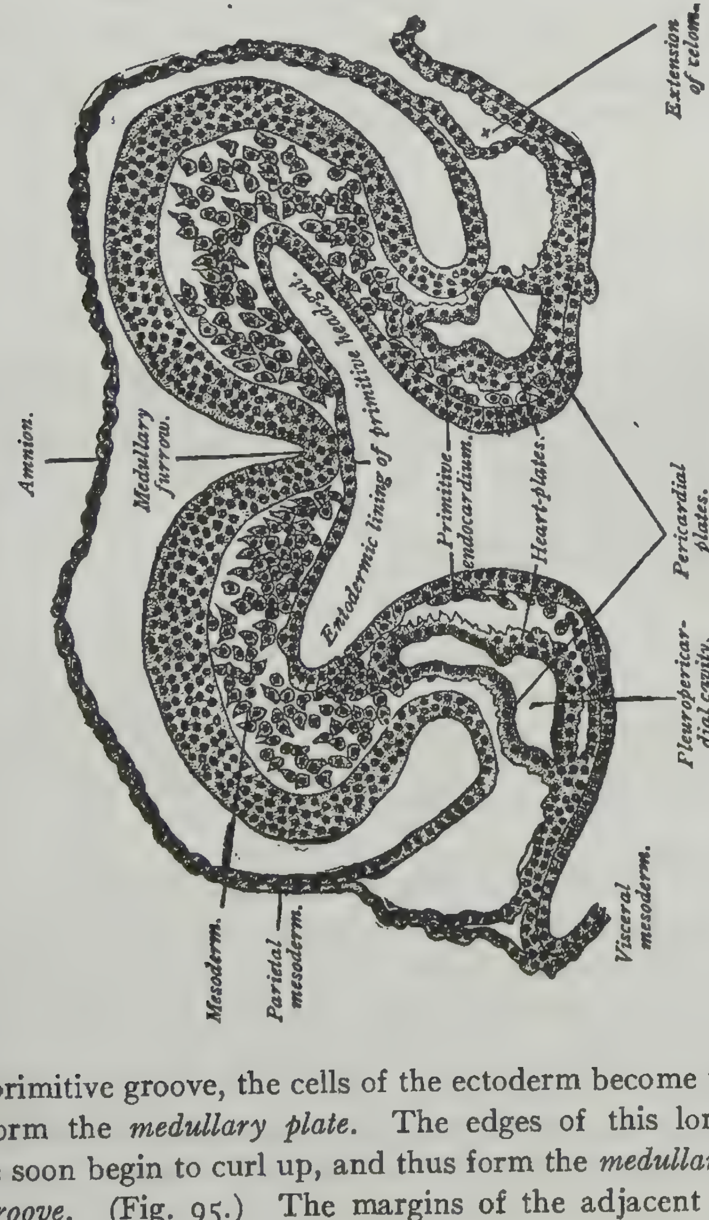
Transverse section of the embryonic area of a fourteen-and-a-half-day ovum of sheep. (*Heisler after Bonnet.*)

the extra-embryonic accessory structures, the *umbilical vesicle, amnion, allantois* and *placenta*. As regards the embryonic body, some of the most prominent occurrences connected with its

development consist in the formation of the *neural canal*, *chorda dorsalis*, or *notochord*, and *mesoblastic somites*.

Neural Canal.—About the fourteenth day, along underneath

Fig. 95.



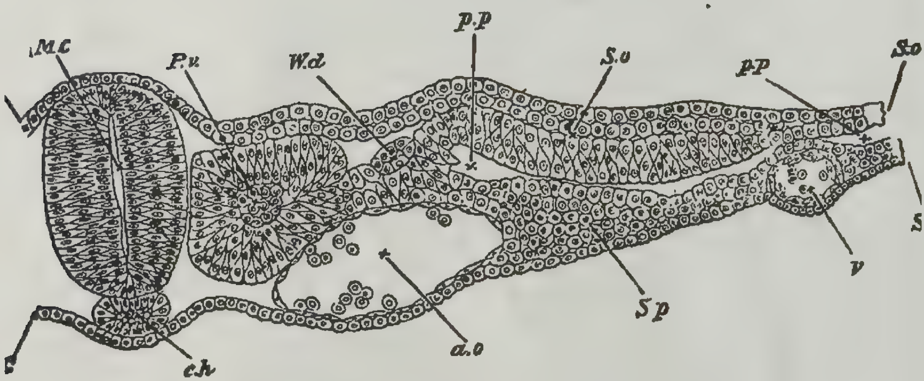
Transverse section of a sixteen-and-a-half-day sheep-embryo. (*Heisler after Bonnet.*)

the primitive groove, the cells of the ectoderm become thickened to form the *medullary plate*. The edges of this longitudinal plate soon begin to curl up, and thus form the *medullary furrow*, or *groove*. (Fig. 95.) The margins of the adjacent ectoderm

are carried up with the curling edges, and constitute the *medullary folds*. Later the edges of the medullary plate meet each other, and join to form a closed canal, the *neural* or *medullary canal*. The edges of the medullary folds unite above, so that the neural canal comes to lie underneath the surface ectoderm. (Fig. 96.) The neural canal is the forerunner of the whole nervous system.

Chorda Dorsalis.—The method of formation of the chorda dorsalis, or notochord, is very similar to that of the neural canal.

FIG. 96.



Transverse section through dorsal region of embryo chick (45 hours).

One-half of the section is represented; if completed it would extend as far to the left as to the right of the line of the medullary canal (*Mc*). *A*, epiblast; *C*, hypoblast, consisting of a single layer of flattened cells; *Mc*, medullary canal; *Pv*, protovertebra; *W.d*, Wolffian duct; *So*, somatopleure; *Sp*, splanchnopleure; *pp*, pleuroperitoneal cavity; *ch*, notochord; *ao*, dorsal aorta, containing blood-cells; *v*, blood-vessels of the yolk-sac. (*Kirkes* after *Foster* and *Balfour*.)

It is a solid, instead of a cylindrical, longitudinal collection of cells, extending along the dorsal aspect of the celom. It is developed from the entoderm. A thickening of the cells of this layer constitutes the *chordal plate*. Its edges curl up in a direction opposite to those of the medullary plate, and carry with them *chordal folds* of the entoderm. When the curling edges have joined to form a solid cylinder of cells, the chordal folds unite over the ventral surface of the cylinder. Figures 95 and 96

illustrate these facts. The notochord is in the line of the future vertebral bodies, but it is not developed into any adult structure.

Somites.—These are masses of cells developed from the axial plates of the mesoderm, lying parallel with and on each side of the notochord. (Fig. 96.) They are in segments, the formation of which begins in the neck and proceeds caudad and cephalad. They are sometimes called the *protovertebræ.* They represent the primitive vertebræ.

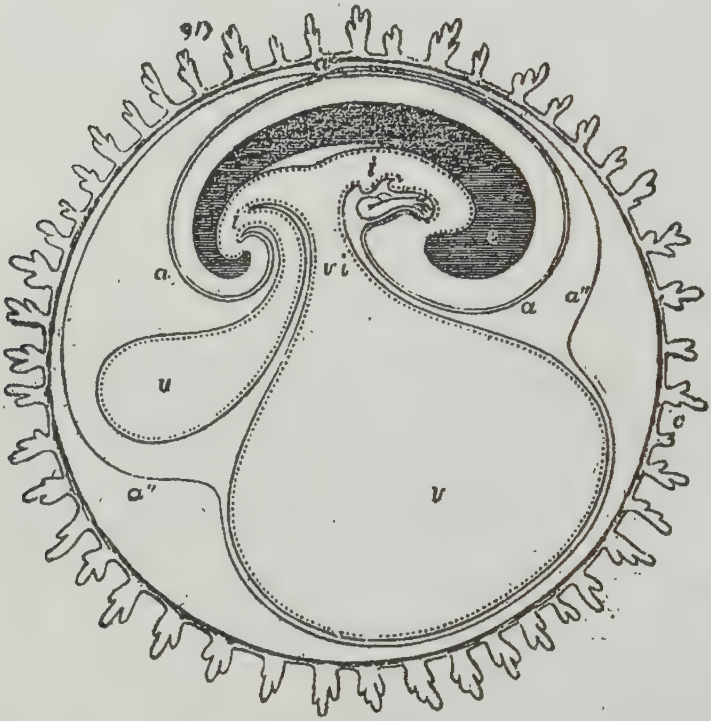
The body begins to assume shape and the fetal appendages to be developed at the same time. The latter are for the protection and nutrition of the embryo. The essential parts of a vertebrate are a *vertebral column* with a *neural canal* above and a *body cavity* below it. The body cavity contains the alimentary canal. The somites representing the vertebral column and the formation of the neural canal have been noticed.

Body Cavity.—At first the embryo, as represented by the embryonal area, is on a level with the remaining surface of the blastoderm. Soon, however, there appears, marking the head of the embryo and with its concavity backward, a crescentic folding in of the blastodermic wall. It is evident on the surface as a simple furrow. This tucking-in finally surrounds the whole embryonal area, and the surface fissure, now oval, becomes deeper and deeper, until those portions of the wall which are being tucked under the embryo approach each other on its ventral aspect and divide the yolk into two communicating cavities. (See Figs. 98 and 99.)

The layers of the blastoderm thus folded underneath the embryo are the *visceral plates.* They form the boundaries of a cavity which still communicates in front, at the site of the future umbilicus, with the yolk-sac. This narrow canal is the *vitelline duct*, and the two cavities communicating through the vitelline duct are the future *alimentary canal* and the yolk-sac, or *umbilical vesicle.* It is to be noticed that the visceral plates embrace both somatopleure and splanchnopleure, and that it is the

ectodermic layers of the splanchnopleure which finally join to form the gut tract, and the somatopleure which forms the ventral

FIG. 97.



Diagrammatic section showing the relation in a mammal between the primitive alimentary canal and the membrane of the ovum.

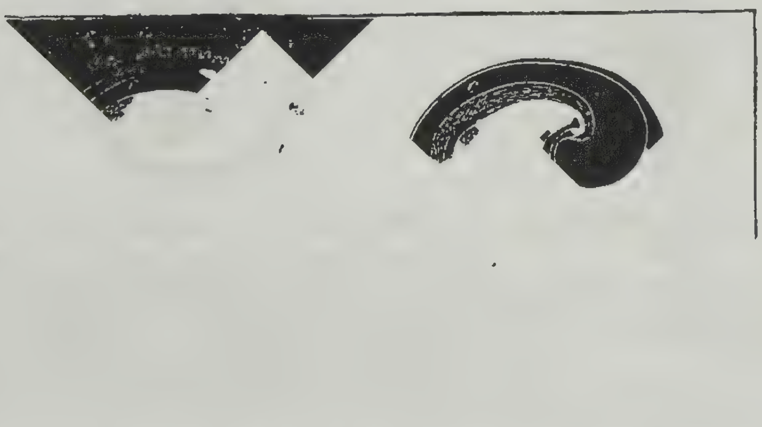
The stage represented in this diagram corresponds to that of the fifteenth or seventeenth day in the human embryo, previous to the expansion of the allantois; *c*, the villous chorion; *a*, the amnion; *a'*, the place of convergence of the amnion and reflexion of the false amnion; *a'' a''*, outer or corneous layer; *e*, the head and trunk of the embryo, comprising the primitive vertebræ and cerebro-spinal axis; *i*, *i*, the simple alimentary canal in its upper and lower portions. Immediately beneath the right hand *i* is seen the fetal heart, lying in the anterior part of the pleuroperitoneal cavity; *v*, the yolk-sac or umbilical vesicle; *vi*, the vitello-intestinal opening; *u*, the allantois connected by a pedicle with the hinder portion of the alimentary canal. (*Kirkes* after *Quain*.)

and lateral walls of the body cavity. The gut tract has the shape of a straight tube occupying the long axis of the embryo and opening into the umbilical vesicle.

Fetal Membranes.

Umbilical Vesicle.—The umbilical vesicle represents that part of the vitellus which has not been constricted off to form the gut tract. (Figs. 97, 98, 99.) It furnishes nutriment to the embryo for a short time and is then largely cut off from the body. It gradually shrivels (Figs. 103, 104), and with that part of the duct external to the abdomen is cast off either before

FIGS. 98 AND 99.



a, chorion with villi. The villi are shown to be best developed in the part of the chorion to which the allantois is extending; this portion ultimately becomes the placenta; *b*, space between the true and false amnion; *c*, amniotic cavity; *d*, situation of the intestine, showing its connection with the umbilical vesicle; *e*, umbilical vesicle; *f*, situation of heart and vessels; *g*, allantois. (*Kirkes.*)

or at parturition. Vessels develop in its walls and absorb the nourishment in it to be conveyed to the embryo. But in the human being more satisfactory arrangements for nutrition are soon made and its function ceases.

Amnion.—When the embryo has become depressed, as it were, into the substance of the blastoderm, and while the body cavity is being formed, the layers of the somatopleure grow up *over* the embryo to meet and blend dorsally. (Figs. 103, 104.) The two layers of which the somatopleure is composed separate,

the outer forming the *false* amnion and the inner the *true amnion.* The false amnion now coalesces with the original vitelline membrane to constitute the false chorion. Evidently there is thus formed a closed cavity, the *amniotic cavity*, between the true amnion and the body of the embryo.

At first the amnion and the embryo are in close contact, but soon the cavity begins to be distended with a fluid, the *liquor*

FIGS. 100 AND 101.

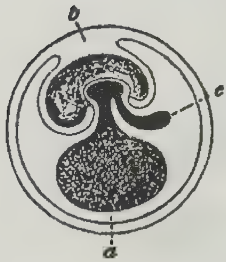


Diagram of fecundated egg.

a, umbilical vesicle; *b*, amniotic cavity; *c*, allantois. (*Kirkes* after *Dalton.*)

Fecundated egg with allantois nearly complete.

a, inner layer of amniotic fold; *b*, outer layer of ditto; *c*, point where the amniotic folds come in contact. The allantois is seen penetrating between the outer and inner layers of the amniotic folds. This figure, which represents only the amniotic folds and the parts within them, should be compared with Figs. 99, 100, in which will be found the structures external to these folds. (*Kirkes* after *Dalton.*)

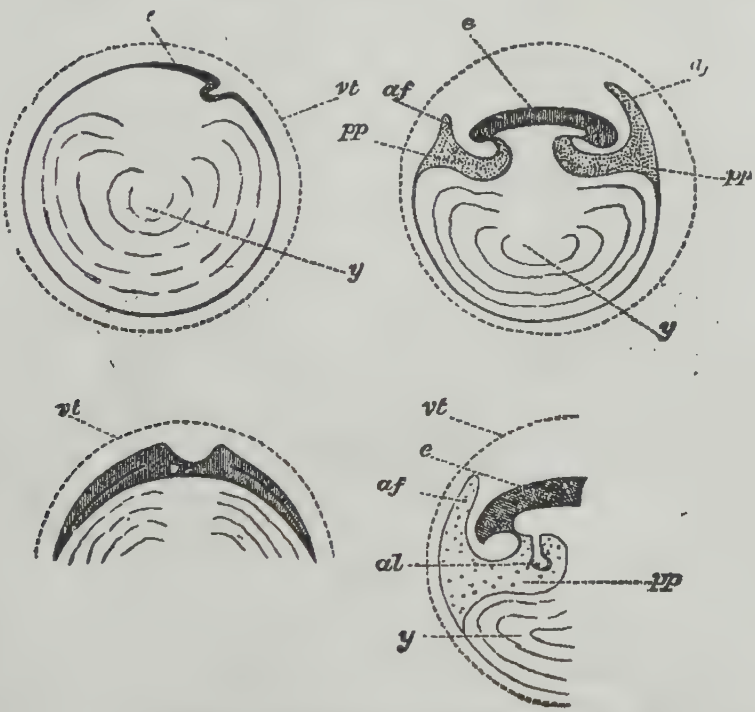
amnii, which increases until it reaches a considerable quantity. It affords mechanical protection to the fetus during intrauterine life, and at labor serves to evenly dilate the cervix. When this has been accomplished is the usual time at which the sac ruptures and the liquor amnii escapes. It also supplies the fetal tissues with water, parts of it being swallowed from time to time.

The cavity between the false amnion and the true amnion is continuous, with the body cavity at the umbilicus.

Allantois.—The allantois grows out from the back part of the intestinal canal into the celom or the body cavity. (Figs. 100, 101.) It is of splanchnopleuric origin. It soon becomes a mem-

branous sac, the walls of which are very vascular. It fills the space between the two amniotic folds and joins the false amnion. Its vessels thus reach the chorion, which is already establishing vascular connections with the mother. Finally they are distrib-

FIG. 102.



This and the two following wood-cuts are diagrammatic views of sections, through the developing ovum, showing the formation of the membranes of the chick. (*Yeo*, after *Foster* and *Balfour*.)

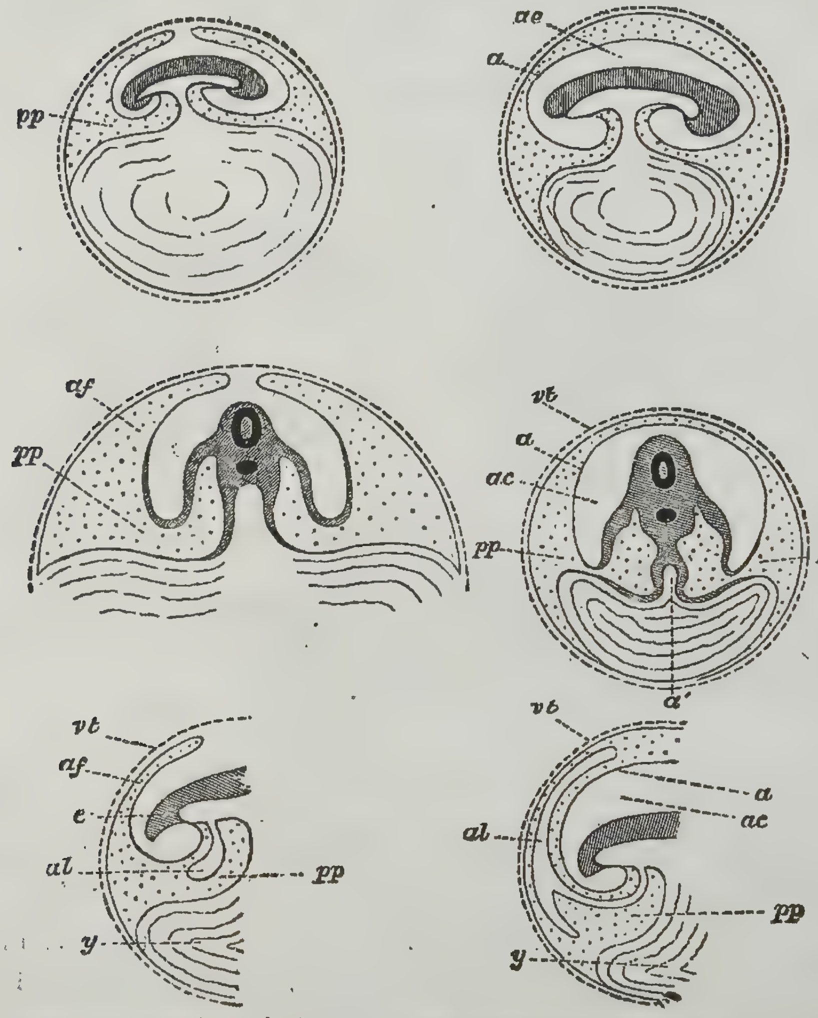
A, B, C, D, E, and *F*, are vertical sections in the long axis of the embryo at different periods, showing the stages of development of the amnion and of the yolk-sac; I, II, III, and IV, are transverse sections at about the some stages of development; i, ii, and iii, give only the posterior part of the longitudinal section to show three stages in the formation of the allantois; *e*, embryo; *y*, yolk; *pp*, pleuroperitoneal fissure; *vt*, vitelline membrane; *af*, amniotic fold; *al*, allantois.

uted only to a certain part (placenta) of the chorion; and as the allantoic vessels anastomose more and more freely with those of the chorion, the umbilical vesicle shrivels, as it is no longer needed. The vessels of the allantois are the two allantoic

arteries and the same number of allantoic veins. The allantois also receives the fetal urine.

As the true placental circulation is established and the visceral

FIG. 103.



e, embryo; *a*, amnion; *a'*, alimentary canal; *vt*, vitelline membrane; *af*, amniotic fold; *ac*, amniotic cavity; *y*, yolk; *al*, allantois.

plates close the abdominal cavity, the allantois is constricted at the umbilicus so as to be divided into two parts. That outside the body shrivels and is cut away with the umbilical

cord at birth, while that inside the body becomes the first part of the male and the whole of the female *urethra*, the *bladder*. and the *urachus*.

Chorion.—The chorion is the outer surrounding membrane of the embryo after the appearance of the amnion. It consists of

FIG. 104.

Diagrammatic sections of an embryo.

Showing the destiny of the yolk-sac, *ys*. *vt*, vitelline membrane; *pp*, pleuroperitoneal cavity; *ac*, cavity of the amnion; *a*, amnion; *a′*, alimentary canal; *ys*, yolk-sac.

three layers. From without inward these are the original vitelline membrane, the false amnion and the allantois. The allantois has been seen to extend around between the two amniotic folds and to blend with the outer. From its formation from these several membranes, the chorion evidently consists of the outer ectodermic, inner entodermic and intervening mesodermic strata.

By the time the impregnated ovum reaches the uterus, the chorion (false at this time) has numerous spike-like projections —villi—over its whole surface. (Fig. 97.) These are at first non-vascular, but soon become vascular by the projection into them of capillaries from the vessels of the allantois. These capillaries probably absorb nutrient matter secreted by the uterine glands. But at the beginning of the third month the villi become much more highly developed over a certain part of the surface of the chorion than at other points, and a more intimate relation is established between their vessels and those of the mother; here the placenta is to be formed.

The Decidua.—The decidua of pregnancy consists of the hypertrophied mucous membrane lining the cavity of the uterus and reflected at a certain point entirely over the developing ovum. Before the ovum reaches the uterus, the mucous membrane of the latter has been undergoing changes, such are mentioned under Menstruation. If fecundation has not taken place, menstruation occurs and the mucosa is discharged under the name of the *decidua menstrualis*. But if conception has occurred, menstruation does not ensue and the uterine mucosa becomes much more thick and spongy. Whether or not it shall be discharged as the decidua of menstruation or be retained to form the decidua of pregnancy is probably a point which is decided while the ovum is yet in the tube.

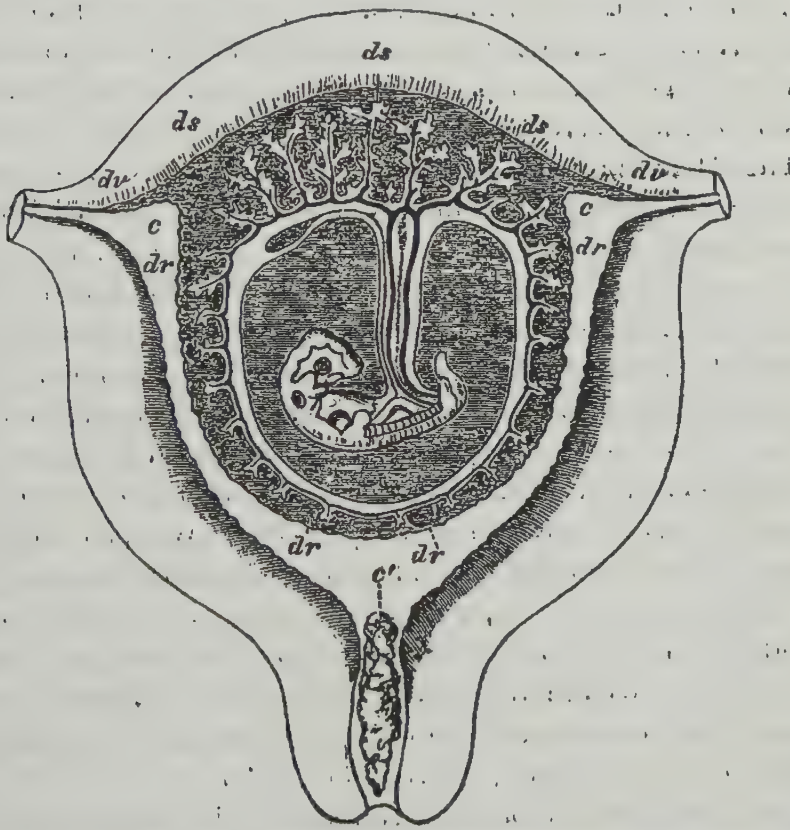
When the fecundated ovum reaches the uterus it becomes attached to the mucous membrane, usually a little to one side of the median line on the posterior wall. The mucous membrane extends over and completely envelops it. This reflected portion is the *decidua reflexa;* that lining the whole uterine cavity is the *decidua vera*, while that part of the decidua vera intervening between the ovum and the uterine wall is the *decidua serotina* and becomes the maternal part of the placenta.

Of course there is at first a considerable cavity left between the reflex and the vera, but as the embryo increases in size the

space becomes smaller and is obliterated by the end of the fifth month. After this time both vera and reflexa undergo retrograde changes due to pressure and become closely attached to the chorion. They are discharged with the membranes at birth.

Placenta.—The placenta is the organ of nutrition for the

FIG. 105.



Diagrammatic view of a vertical transverse section of the uterus at the seventh or eighth week of pregnancy.

c, *c*, *c'*, cavity of uterus, which becomes the cavity of the decidua, opening at *c*, *c*, the cornua, into the Fallopian tubes, and at *c'* into the cavity of the cervix, which is closed by a plug of mucus; *dv*, decidua vera; *dr*, decidua reflexa, with the sparser villi imbedded in its substance; *ds*, decidua serotina, involving the more developed chorionic villi of the commencing placenta. The fetus is seen lying in the amniotic sac; passing up from the umbilicus is seen the umbilical cord and its vessels passing to their distribution in the villi of the chorion; also the pedicle of the yolk-sac, which lies in the cavity between the amnion and chorion. (*Kirkes* after *Allen Thomson*.)

fetus after about the end of the third month. Through it the vessels of the fetus and those of the mother are brought into most intimate relations.

It has been said that the villi of the chorion in one locality become very highly developed. This is at the site of the reflection of the *decidua serotina* and is the *chorion frondosum*. The union of these, with certain other developments, constitutes the placenta.

The decidua serotina becomes very spongy. It is filled with sinuses, into which the enlarged villi of the chorion frondosum project. The sinuses are filled with maternal blood, while the capillaries of the villi contain fetal blood. There is *no direct connection* between the vessels of mother and child, but the thin lining of the villi and sinuses allows free interchange of materials by osmosis.

It seems that the interchange is under the influence of two sets of cells, each disposed in a single layer—one belonging to the maternal and the other to the fetal part of the placenta. These layers of cells are situated on either side of the *membrane of the villus*. They seem to take out of the maternal blood materials needed for the nutrition of the fetus, and out of the fetal blood materials which require removal. The maternal blood performs both alimentary and respiratory functions for the fetus.

The placenta as a whole is discoid in shape. Its fetal surface is concave and covered by the amnion. The mass has a diameter of 4–5 in., and a thickness of half an inch. The villi receive blood from the allantoic or umbilical arteries; it is returned by the umbilical vein.

At labor uterine contractions detach the placenta and the decidua and expel them from the womb. The separation takes place in the deeper part of the *maternal* placenta, or decidua serotina, so that the mass discharged represents both the fetal and maternal portions. The vessels entering the sinuses do so obliquely; consequently uterine contractions at birth very

effectually check the hemorrhage which separation of the placenta occasions.

Umbilical Cord.—The umbilical cord is made up of the vessels which convey blood between the placenta and fetus, together with the remnants of the umbilical vesicle and allantoic stalk, all of which are held together by the jelly of Wharton, a species of connective tissue.

The outgrowing allantois has developed in it the two allantoic arteries and veins. By the time the placenta is formed the allantoic stalk has become much elongated, and the allantoic vessels extend into the fetal placenta (chorion frondosum) and become now the *umbilical vessels*. The two veins blend to constitute a single umbilical vein, but the arteries remain separate. The *vein* enters the fetal body at the umbilicus, passes to the under surface of the liver and divides in a manner to be noted presently. After birth the intra-abdominal portion atrophies, and is the round ligament of the liver. The two umbilical arteries issue at the umbilicus. Their intra-abdominal portions are the fetal hypogastric arteries.

The average length of the umbilical cord is about twenty-one inches. It appears to be twisted on account of the spiral course of its relatively long arteries. It is usually attached near the center of the fetal surface of the placenta.

Condition of the Fetal Membranes at Birth.—The membranes discharged with the placenta at birth are, from without inward, the *decidua vera*, *decidua reflexa*, *chorion* and *amnion*. The amniotic fluid, in which the fetus floats, reaches its maximum amount at about the sixth month. It is sufficient then to force the amnion closely against the chorion, covered by the decidua reflexa; these last named (chorion and reflexa) are in turn forced everywhere against the decidua vera. The result is that all four become practically one membrane, though the union between amnion and chorion is not so close as that between the other layers. These membranes constitute, then, a sac

filled with fluid. The sac is ruptured in labor, and the child escapes through the rent. Afterwards the decidua vera and placenta are detached, and escape together as the "after birth."

Development of the Circulation.—The development of the circulation may be considered in these stages: (1) Vitelline circulation, (2) placental circulation, (3) adult circulation. The heart is the propelling organ in all these.

1. **Vitelline Circulation.**—The blood and vessels make their appearance almost as early as the primitive groove. Certain blastodermic cells are transformed into both red and white corpuscles. They are larger than the adult's cells and both are nucleated. Blastodermic cells also group to form small tubes, which constitute the *area vasculosa.* At the same time mesoblastic cells develop two tubes, one along each side of the body, which soon unite to form a single one, representing the heart. It becomes enlarged and twisted upon itself, and pulsations begin in it at a very early date. The heart is in the median line and gives off two arches which unite below to form the abdominal aorta. From the arches pass branches to the area vasculosa, which now form a nearly circular plexus around the embryo. Two of these branches, larger than the others, enter the umbilical vesicle and become the *omphalo-mesenteric arteries;* there are two corresponding veins. This circulation through the omphalo-mesenteric vessels and the area vasculosa does not continue long in the human being. As soon as the allantois is formed and the placental circulation begins to be set up, the omphalo-mesenteric vessels are obliterated and the place of the first circulation is taken by the second.

Development of the Heart.—The tube just mentioned as representing the heart has communicating with it two veins at its lower extremity and two arteries at its upper. Soon the tube becomes twisted upon itself so that the upper (arterial) is thrown in front of the lower (venous). The loop is V-shaped and is the outline of the future ventricles. Afterward a constriction

forms the auricle. At this time the heart consists of a single ventricle and a single auricle. Later the ventricular and auricular septa are formed. The latter appears after the former and is incomplete; the opening left between the auricles is the *foramen ovale.*

2. **Placental Circulation.**—As the allantois is developed and the vitelline circulation is abolished, the hypogastric arteries are given off first from the aorta, but later (with the development of the vessels of the lower extremities) they are pushed down, as it were, so that they take origin from the internal iliacs. They pass to the umbilicus and thence to the placenta by the cord. Blood is at first returned from the placenta by two umbilical veins, but these soon fuse into one.

Object of Placental Circulation.—Since the activity of the respiratory and alimentary tracts has not been established, their functions must be performed by those of the mother and the necessary materials supplied from her blood. Consequently there must be a continual passage of fetal blood to and from the *placenta* to discharge effete matter and to absorb nutriment. Certain modifications of the circulatory apparatus, not requisite after birth, are necessary to bring this about.

Course of Fetal Circulation.—The umbilical vein containing blood enriched with oxygen and other materials enters the body at the umbilicus and passes to the under surface of the liver. Here it divides into two branches. The larger joins the portal vein and enters the liver; the smaller is the *ductus venosus,* which enters the ascending vena cava.

The ascending vena cava, when it enters the right auricle, therefore, contains blood from the lower extremities, blood which has come from the placenta *directly* through the ductus venosus, and blood which has come from the placenta *indirectly* through the liver. Considering that blood from the body of the fetus is venous and that blood directly from the placenta is arterial, the contents of the ascending vena cava are *mixed* when

they enter the heart. The *Eustachian valve*, together with the *direction* of the entering current, causes the blood from the

FIG. 106.

Diagram illustrating the circulation through the heart and the principal vessels of a fetus. (From *Yeo* after *Cleland*.)

a, umbilical vein; *b*, ductus venosus; *f*, portal vein; *e*, vessels to the viscera; *d*, hypogastric arteries; *c*, ductus arteriosus.

ascending vena cava to pass through the foramen ovale into the *left auricle*.

Blood from the upper extremities (impure) enters the right auricle through the descending vena cava. The Eustachian valve and the direction of the current here again cause this blood to enter the *right ventricle*. There is supposed to be very little mingling of blood from the two venæ cavæ as it passes thus through the right auricle. At the same time the blood which has entered the left auricle through the foramen ovale, augmented slightly by blood from the ill-developed pulmonary veins, passes into the left ventricle. The ventricles now contract simultaneously.

Blood from the *right ventricle* (impure) passes in small part through the pulmonary artery to the lungs, but chiefly through a tube, the *ductus arteriosus*, into the descending part of the *aortic arch*.

Blood from the *left ventricle* (mixed) enters the aorta and goes to the system at large.

The vessels going to the head and upper extremities are given off from the aortic arch before it is joined by the ductus arteriosus. Since the ductus arteriosus contains impure blood, the supply going to the upper extremities is purer than that going to the lower.

Of the blood which passes down the aorta a part leaves by the hypogastric arteries, to go again to the placenta, while the other part is distributed to the trunk and lower extremities.

It thus appears that the liver is the only organ of the fetus which receives pure blood, and that the head and upper extremities are better provided for in this respect than are the lower parts. This may account for the relatively large liver of the fetus, and for the fact that the upper extremities are better developed than the lower.

The *ductus arteriosus*, *ductus venosus*, *foramen ovale*, *Eustachian valve*, *hypogastric* (*umbilical*) *arteries* and the *umbilical vein* are the organs which distinguish the placental circulation, and they all partially disappear after birth, as will be immediately seen.

3. **Adult Circulation.**—The circulation as it exists in the adult has been described. It is only necessary to see what changes mark its establishment.

When the child is born detachment of the placenta, or ligation of the cord, stops the placental circulation. The first noticeable effect comes from the consequent deoxygenation of the blood. The respiratory center is stimulated and the child gasps to fill the hitherto collapsed lungs with air. Owing to the diminished resistance in the expanded lungs, the pulmonary artery begins to carry most of the blood from the right ventricle, and the ductus arteriosus commences to atrophy. Before birth, too, the Eustachian valve becomes less distinct and the foramen ovale partly closes. At labor a kind of valve guards the opening of the foramen ovale and allows the escape possibly of a little blood from the right into the left auricle, but none in the opposite direction. It commonly closes about the tenth day of extrauterine life. The ductus arteriosus is reduced to the condition of an impervious fibrous cord between the third and tenth days after birth.

The hypogastric arteries, umbilical vein and ductus venosus are closed between the second and fourth days. That part of each hypogastric artery between the internal iliac and the upper lateral part of the bladder remains in adult life as the superior vesical artery; the part between this point and the umbilicus is that which atrophies. The umbilical vein remains as the round ligament of the liver. The ductus venosus is represented by a fibrous cord in the fissure for the ductus venosus in the liver.

The Skeleton.—The appearance of the notochord and of the protovertebræ, or somites, has been observed. The notochord becomes a thin line of soft cartilage, around which the bodies of the *vertebræ* are developed, though it does not itself become those bodies. The protovertebræ were seen to lie longitudinally on either side of the notochord. These grow around the neural

canal dorsally and the notochord ventrally to form the vertebræ. From them also are developed the muscles and skin of the back.

The *cranium* is developed as a modification of the vertebral column.

All the bones are in early fetal life cartilaginous or membranous. Centers of ossification appear at one or more points in each bone.

The bones of the extremities are not at first separate. They bud out from the upper and lower parts of the trunk, to be subdivided later.

Nervous System.—The origin of the nervous system has been indicated in describing the neural canal. The mesodermic cells multiply and fill the tube, until only the canal of the spinal cord is left. Headward the neural canal terminates in a dilated extremity, which soon becomes divided into three *vesicles*, *anterior*, *middle* and *posterior*. From these are developed the different parts of brain. Some of these parts develop much more rapidly than others, and we thus account for the predominant size of the cerebrum. At first there are no cerebral convolutions, but later the cavity of the cranium seems too small for the brain and the characteristic infoldings occur.

The **eye** is formed by the projection of the optic vesicle from the side of the anterior brain vesicle.

The **internal ear** is formed by the projection of the auditory vesicle from the posterior brain vesicle.

The **alimentary canal** is formed by being pinched off from the mesodermic layer of splanchnopleure. It communicates for some time by means of the vitelline duct with the umbilical vesicle. When cut off from the latter it is a straight tube, occupying the long axis of the body just in front of the vertebral column, and is divided into the foregut, hindgut and a central part. Later it communicates above with the pharynx and mouth and opens below upon the external body surface (anus). The

liver and pancreas are developed from protrusions from the sides of the duodenum.

The **bladder** has been seen to be that part of the allantoïs which is constricted off and remains in the body.

The **lungs** are developed from the esophagus and at first lie in the abdominal cavity; but the formation of the diaphragm fixes them in the thorax.

The **kidneys** are developed from the Wolffian bodies. These bodies are embryonic structures only. Each is a tube lying parallel to the vertebral column on either side of it. This tube consists of a collection of tubules, which unite to form a common excretory duct. This duct joins the corresponding one from the opposite side to empty into the alimentary canal opposite the allantoic stalk. Outside the Wolffian bodies are two other ducts, the ducts of Müller. They also enter the intestine.

The Wolffian body finally gives place to the kidney, from which the ureter is developed.

In the female the ducts of Müller become the **tube, uterus** and **vagina.** In the male they atrophy.

Just behind the Wolffian bodies are developed the **ovaries** or the **testes,** as the case may be.

The development of a few of the organs has thus been simply referred to.

Satisfactory explanation of these procedures can be given only in extended works on embryology, and this section may be closed with the subjoined table of development, which is abbreviated from one by Heisler:

First Week.—Segmentation and passage of ovum to uterus.

Second Week.—Ovum in uterus. Decidua reflexa present. Entoderm and ectoderm layers formed—also mesoderm. Embryonal area, primitive streak in primitive groove. Chorion

and villi. Amnion folds. Umbilical vesicle partly formed. Vascular area. Two primitive heart tubes. Gut tract partly formed.

Third Week.—Body indicated. Dorsal outline concave. Vitelline duct. Amnion. Allantoic stalk. Visceral arches. Heart divides. Vitelline circulation begins. Gut tract still connected with umbilical vesicle. Liver evagination begins. Anal plate. Pulmonary protrusion. Wolffian bodies. Neural canal. The brain vesicles. Optic and otic vesicles. Olfactory plates. Notochord.

Fourth Week.—Flexion of body. Yolk-sac largest size. Somites well formed. Allantois grows. Vitelline circulation complete. Allantoic vessels developing. Pharynx, esophagus, stomach and intestine differentiated. Pancreas begins. Pulmonary protrusion bifurcates. Ventral roots of spinal nerves. Limb buds apparent.

Fifth Week.—Umbilical vesicle begins to shrink. Cord longer and spiral. Length of fetus two-fifths of an inch. Primitive aorta divides into aorta and pulmonary artery. Intestine shows loops. Bronchi divided. Ducts of Müller. Epidermis. Olfactory lobe. Eyes move forward. Limb buds segment. Digitation indicated.

Sixth Week.—Umbilical vesicle shrunken. Amnion larger. Vitelline circulation supplanted by allantoic. Teeth indicated. Duodenum, cecum. Rectum. Larynx. Genital folds and ridges. Dorsal roots of spinal nerves. Eye-lids. Lower jaw and clavicle begin to ossify. Vertebræ and ribs cartilaginous. Fingers separate.

Seventh Week.—Body and limbs well defined. Heart septa complete. Transverse and descending colon. Nails indicated. Cerebellum indicated. Muscles recognizable. Ossification in cranium and vertebræ begins.

Eighth Week.—Head somewhat elevated. Parotid gland. Gall bladder. Müllerian ducts unite. Genital groove. Mam-

mary glands begin. Sympathetic nerves. Nose discernible. Additional centers of ossification.

Ninth Week.—Weight, three-fourths of an ounce. Length, one and a quarter inches. Pericardium. Anal canal. External genitals begin to indicate sex. Ovary and testis distinguishable. Kidney characteristic. External ear indicated.

Third Month.—Weight, four ounces. Length, two and three-quarter inches. Chorion frondosum. Placental vessels. Tonsil. Stomach rotates. Vermiform appendix. Liver large. Epiglottis. Ovaries descend. Testes in false pelvis. Hair and nails. Development of different parts of brain. Limbs have definite shape.

Fourth Month.—Weight, seven and three-quarter ounces. Length, five inches. Head one-fourth of entire body. Germs of permanent teeth. Distinction of external genitals well marked. Spinal cord ends at end of coccyx. Eye-lids and nostrils closed.

Sixth Month.—Weight, two pounds. Length, twelve inches. Amnion at maximum size. Trypsin in pancreatic secretion. Air vesicles. Eye-lashes. Lobule of ear characteristic.

Seventh Month.—Weight, three pounds. Length, fourteen inches. Meconium. Ascending colon. Testes at internal rings. Cerebral convolutions evident. Differentiation of muscular tissue.

Eighth Month.—Weight, four to five pounds. Length, sixteen inches. Body more plump. Ascending colon larger. Testes in inguinal canal. Skin brighter color. Nails project beyond finger tips.

Ninth Month.—Weight, six to seven pounds. Length, twenty inches. Meconium dark green. Testes in scrotum. Labia majora in contact. Spinal cord ends at last lumbar vertebra. Ossification centers completed.

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